6.0 INSPECTION OF SPILLWAYS AND OUTLETS

6.1 INTRODUCTION

The purpose of a dam safety inspection is to identify deficiencies that potentially affect the safety of the dam. An inspector should develop a methodical procedure for visually inspecting a dam to ensure that all features and areas are examined and to minimize the amount of time spent in the field. This chapter focuses on the visual inspection of dam spillways and outlet structures. These structures are part of the appurtenant works of embankment and concrete dams.

Figure 6-1 Principal spillway utilizing a riser as the control; this is the most common type of spillway in Indiana. The riser has a trash rack over the top constructed with concrete and steel bars.

The purpose of this chapter is to help dam owners and inspectors identify common problems that affect the performance of spillways and outlets in dams, and outline visual inspection procedures. The general technique for visually inspecting spillways and outlets is to examine each feature closely from a short distance to see the entire structure clearly. All visible defects should be identified, measured, evaluated, and recorded. Some form of report or documentation with recommendations for corrective action is then prepared for the owner's project files. Some spillways and outlets may be difficult to access and may require special equipment to complete the visual inspection.

The spillway system consists of the structures over or through which base inflows and flood flows are safely discharged. If the flow is controlled by gates, it is a **controlled spillway**; if the elevation of the spillway crest is the only control, it is an **uncontrolled spillway**. Uncontrolled spillways are the most commonly used type in Indiana. Figure 6-1 shows an uncontrolled spillway; the control section is the crest of a riser pipe.

The inspector should review the owner's project files for design capacity calculations to make sure that the dam spillway system can safely handle the design storm event. The inspector should look for signs of high water level when he/she is performing the visual inspection.

Spillways typically include all or most of the following four components, each serving a different function: (1) entrance channel, (2) control section, (3) outlet channel, and (4) terminal structure. The **entrance channel** conveys water from the reservoir to the control section and is usually required except for drop inlet spillways located in the reservoir and overflow spillways on concrete dams. The **control section** governs the spillway discharge. Control sections may be orifice-like openings, conduit entrances, or a crest in the form of a shaped weir or a sill. They may be either unregulated or regulated by gates, flashboards, and valves. The **outlet channel** conveys and returns the water to the stream beyond the dam or into other topographic depressions beyond the reservoir basin. The channel may be on the face of a concrete dam; an open channel, lined or unlined, in natural formations; a conduit through or beneath the dam; or a tunnel through an abutment. Free falling flows from overpouring crests require no discharge channel. The outlet channel should be positioned so that it does not erode the embankment and foundation. The inspector should be on the lookout for outlet channels that discharge near the embankment toe. The **terminal structure** prevents excessive erosion of the stream channel or damage to adjacent structures and the dam from the high-energy spillway discharges. Stilling basins, roller buckets, baffled impact-type basins, and lined aprons are commonly used as terminal structures.

Spillway systems typically consist of a **principal spillway** and an **auxiliary spillway** (often referred to as an **emergency spillway**). The principal spillway is the first-used spillway during base inflow and flood flows. The auxiliary spillway is a secondary spillway designed to operate in conjunction with the principal spillway; when used, the principal spillway is designed to pass floods likely to occur frequently, and the auxiliary spillway is set to operate only after such small floods are exceeded. The combination of the principal and auxiliary (or emergency) spillway should safely pass the design storm event without overtopping the unprotected portion of the embankment.

The following types of spillways are commonly found at dams; however, many variations of these spillways may be used. Figure 6-2 illustrates some commonly used types of spillways. The most commonly used spillways used in Indiana include the drop inlet (or shaft) spillway used as the principal spillway, and an open channel used as an auxiliary, or emergency spillway.

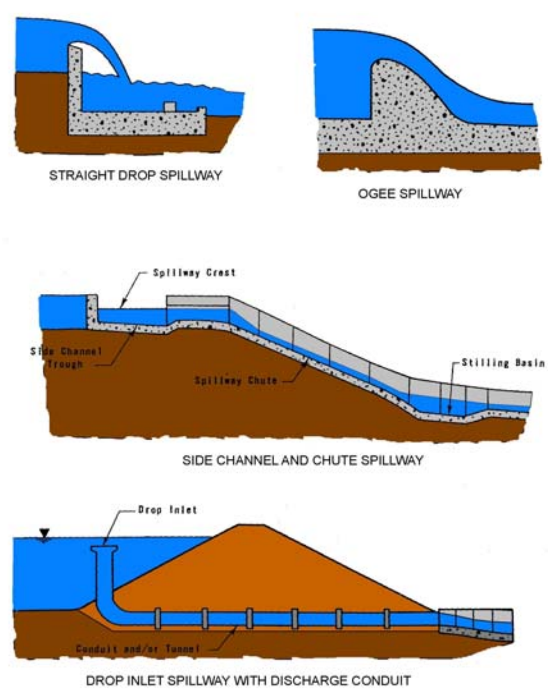


Figure 6-2 Commonly used types of spillways.

Drop Inlet Spillway (also called Morning Glory Spillway, or Shaft Spillway) - A vertical or inclined shaft into which flood water spills and then is conducted through, under, or around a dam by means of a conduit or tunnel. If the upper part of the shaft is splayed out and terminates in a circular horizontal weir, it is termed a "bellmouth" or "morning glory" spillway. The vertical portion of the spillway is called the **riser**. The risers are typically reinforced concrete pipes or boxes. Shaft spillways are commonly used in Indiana as the principal spillway, and are usually referred to as drop inlets or risers.

Figure 6-3 Concrete-lined side channel spillway with stilling basin at outlet.

Side Channel Spillway - A spillway located on insitu ground to the side of the embankment. Emergency spillways are usually side channel spillways; however, principal spillways may also be side channel spillways. Side channels may be constructed with energy dissipation structures, such as baffles or stilling basins, to reduce discharge velocity and energy.

Conduit Spillway - A spillway consisting of a closed channel, or conduit, that conveys the reservoir discharge under or through the dam embankment. The closed channel may be a vertical, horizontal, or inclined shaft and may be used in conjunction with most forms of control sections, including overflow crests, drop inlet entrances, and side channel crests. Conduit spillways are sometimes used without another type of control structure.

Ogee Spillway - An overflow weir in which the cross section of the crest, downstream slope and bucket have an “S” (or ogee) form of curve. The shape is designed so that the underside of the nappe matches the upper extremities of the weir.

Spillways are critical to the safe operation of every dam and must be inspected very closely. Many problems that occur at spillways may not be visible until damage or failure occurs. This is particularly true with problems that develop along or under conduits in embankments, or under concrete linings. The riser on a shaft spillway is almost always submerged in the reservoir, making it difficult if not impossible to examine all parts of the spillway. Boat access may be required on some, while professional scuba divers may be required to inspect others. For this reason, inspectors must be alert for any signs of deterioration or damage that may be present, but may not be visible during a surface inspection.

Figure 6-4 illustrates an embankment dam configuration that is commonly used in Indiana. The principal spillway is a concrete shaft spillway with a rectangular riser and a circular, concrete conduit for discharging the riser flows. The emergency spillway is a side channel spillway constructed on insitu ground. Anti-seep collars have been used to control seepage along the conduit, however they are no longer recommended.

Seepage diaphragms are newer technology and are replacing the anti-seep collars as the preferred method of seepage control. A diaphragm is an engineered filter placed at intervals along the conduit (with one placed close to the pipe outlet) that prevents seepage water from removing the soil from around or under the conduit. Anti-seep collars may contribute to piping problems and the embankment should be closely inspected for problems if they are used.

The outlet is the structure through which water can be freely discharged from a reservoir. Outlets are used to drawdown the reservoir level in dams, or to maintain a desired flow downstream of the dam. An outlet may also be referred to as a reservoir drain.

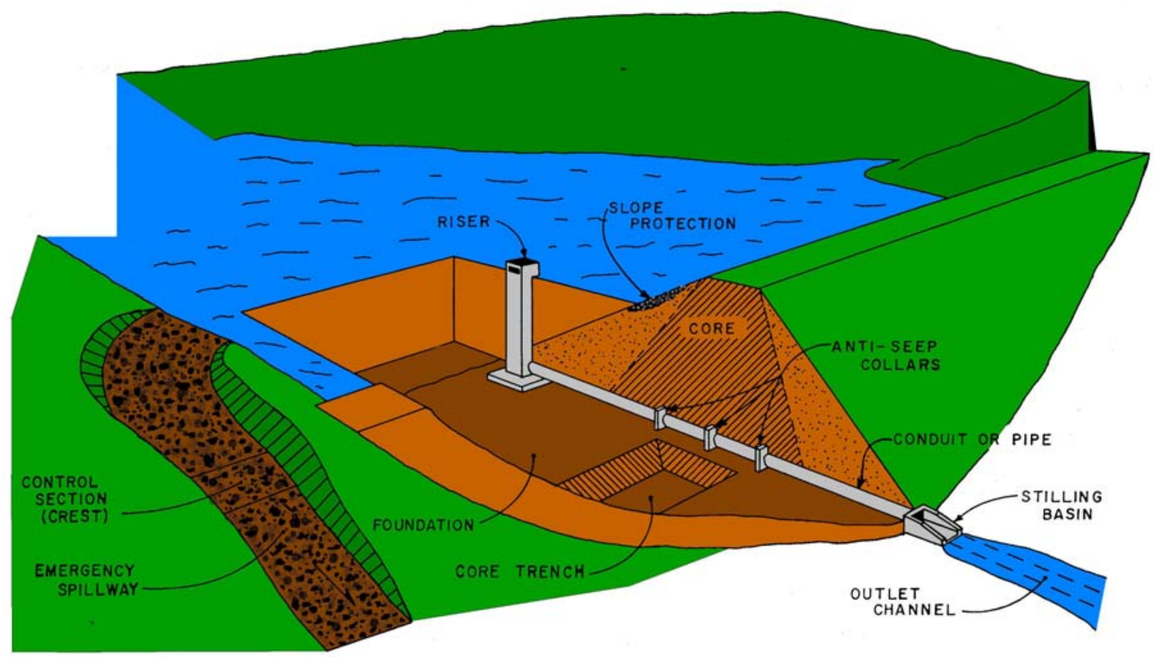


Figure 6-4 Section of a typical dam in Indiana, illustrating the principal and emergency spillways. Although anti-seep collars were commonly used in the past, they are no longer recommended for use.

The primary function of the outlet (also called outlet works, or outlet system) is to provide for the controlled release of water from the reservoir behind the dam. The outlet system is used to release water downstream for irrigation, dam repairs, emergencies, and other uses. The size of the outlet system is determined by the rate of demand downstream, or the desired rate of drawdown that may be needed for maintenance. Except in an emergency, the rate of drawdown of the reservoir should be slow; not exceeding one foot per 24-hour period is typical. In an emergency, drawdown should be accomplished as rapidly as possible without creating additional peril to the dam, its appurtenances, or the area downstream.

Outlet works components may include the following: entrance channel, intake structure, waterway or conduit, control section, terminal structure, access shafts, bridges, and tunnels, and operation/ maintenance stations.

The entrance channel (if present) conveys water to the intake structure of the outlet works. The intake structure establishes the ultimate drawdown level, guards against entry of trash, and may incorporate water control devices (valves) for flow regulation or closure devices for dewatering the outlet works during visual inspection and maintenance. Intake structures may be vertical or inclined towers, drop inlets, or submerged, box-shaped structures. Intake elevations are determined by the head needed for discharge capacity, storage capacity for siltation, the required amount and rate of withdrawal, and the desired maximum drawdown level.

The waterway conveys the released water from the intake structure to the point of downstream release. Waterways may be steel-lined sluiceways or ports through concrete dams, lined or unlined tunnels in abutments, or from the reservoir basin elsewhere, open channels, or closed conduits beneath the dam. Closed waterways may be designed for pressure and non-pressure flow. Pressure pipelines and penstocks may be extended through non-pressure conduits and tunnels, affording access and pressure relief.

The control section regulates the flow of water through the outlet works and may be located at the upstream or downstream limits of the waterway, at intermediate positions, or at several positions. It houses and supports control devices that proportion or shut off outflow. Types of valves and gates used for control devices include slide gates; commercial gate valves; butterfly valves; ring follower, fixed-wheel, and roller train leaf gates; needle, tube, jetflow, hollow-jet, and Howell-Bunger valves; and bottom-seal and top-seal radial gates. For satisfactory performance, the type of valve or gate must be matched to service conditions such as maximum head, flow velocity, in line or free discharge, fully open, closed, or partially open, and unbalanced or balanced head operation.

The terminal structure delivers the flows to the point of downstream release. The need for and the type of terminal structure are determined by the purpose of the outlet works. The terminal structures can be separate structures similar in principle to those for spillways, or the outlet releases may be conveyed through the spillway discharge conduit and terminal structure.

The inspector should visually inspect the outlet and all of its components. Arrangements should be made with the dam owner to have someone operate the outlet; the inspector should not operate the outlet to avoid potential liability issues involving the release of water, or possible breakage or sticking (in open position) of control valves.

6.2 ITEMS OF CONCERN

There are four general types of problems that can prevent a spillway or outfall from functioning properly: (1) cracks and structural damage; (2) inadequate erosion protection; (3) deterioration or lack of maintenance; and (4) obstructions. As soon as any of these problems is identified, remedial steps should be taken to correct the defect. Each of these types of problems is described in detail in this chapter. Additionally, special concerns of conduits and outlets are discussed separately, including visual inspection guidelines and testing procedures.

Table 6-1
Items of Concern

1. Cracks & Structural Damage
2. Inadequate Erosion Protection
3. Deterioration
4. Obstructions

Special Concerns:
- Conduits
- Outlets

Figure 6-5 This dam's open channel spillway used a concrete control section; note that it failed and was almost totally washed away.

The spillway is a very important part of a dam. If it has not been designed with adequate capacity, or is not constructed and maintained properly, overtopping of the embankment may occur during a large storm. This could cause failure of the dam or its components and serious damage to downstream properties, or even death of downstream residents. A spillway should always be kept free of obstructions, have the ability to resist erosion, and be protected from deterioration. A dam and reservoir represent not only a potential public hazard, but also a substantial investment. The dam's owner can identify any changes in previously noted conditions that indicate a safety problem. A conscientious annual maintenance program should address and control most of the conditions described in this chapter. Quick corrective reaction to conditions requiring attention will promote the safety and long life of the dam and possibly prevent costly future repairs. The inspector must visually examine spillways and outlets for potential deficiencies to ensure the continued safety of the dam.

In general, spillways are either open channels or conduits. Open channel spillways are easier to inspect because they are typically easier to access. Steep sidewalls or flowing water in open spillways may make visual inspection dangerous for the inspector. Many dams in Indiana use pipes (or conduits) that serve as principal spillways or outlet structures. Pipes placed through embankments may be difficult to construct properly, can be extremely dangerous to the embankment if problems develop after construction, and are usually difficult to inspect and repair because of their location. Maximum attention should be directed to visually inspecting and maintaining these structures.

Frequent visual inspection of the spillway and outlet conduits is necessary to ensure that they are functioning properly. All conduits should be inspected thoroughly once a year as part of the maintenance inspection program. Conduits which are 30 inches or more in diameter can be entered and visually inspected with proper precautions and equipment. The conduits should be inspected for improper alignment (sagging), elongation, separation, displacement at joints, deformation, undermining, cracks, leaks, surface wear, loss of protective coatings, corrosion, and blockage. Problems with conduits occur most often at joints, therefore special attention should be given to the joints during the visual inspection. The joints should be checked for gaps caused by elongation or settlement and loss of joint filler material. Open joints can permit erosion of embankment material or cause leakage of water into the embankment during pressure flow. The outlet should be checked for signs of water seeping along the exterior surface of the pipe. A depression in the soil surface over the pipe may be a sign that soil is being removed from around the pipe.

The inspector must be careful when entering conduits. These areas are potentially confined spaces and may contain noxious gases, or may lack sufficient oxygen. If in doubt, the inspector should use a portable gas meter to check the air in a conduit before entering. Conduits also present potential hazards to the inspector's physical safety.

The inspector should look carefully for signs of structural damage to spillways and outlets that could create a safety hazard. Structural damage usually results from foundation problems or settlement of fill material around or under the structure. Cracking and displacement of the structure are typical outward signs of structural damage.

Figure 6-6 The valve stem for the outlet in this dam is conveniently located in the riser; notice the rust forming on the metal components.

Outlets (drains or drawdown structures) should be operated every time formal technical or maintenance inspections are performed. In addition, they should be operated at least twice annually and especially just before the annual flood season, typically March in Indiana. This will help keep the equipment in working order and verify its performance. Unused outfall valves and controls can become corroded or blocked with sediment, so routine testing can help maintain these devices. Precaution must be exercised to prevent downstream flooding by releasing too much water.

A visual inspection of the outlet may require advance planning to allow outflows to be shut off and inundated areas to be pumped out. Inspection by the owner or his representative can usually determine if a problem exists with the outlet. In most cases a qualified dam safety professional will be required to recommend corrective action when problems are found.

The remainder of this chapter focuses on the visual inspection and identification of specific problems that may be found on spillways and outlets. The information is presented by the type of deterioration (i.e., cracks and structural damage, inadequate erosion protection, deterioration, and obstructions) for the various types of spillways and outlets that may be encountered.

6.3 CRACKS AND STRUCTURAL DAMAGE

Minor cracking is sometimes present on concrete-lined spillways, concrete pipes, and conduits. Significant cracking, however, often causes vertical and/or horizontal displacement, and misalignment of the structure. Structural damage may affect any type of spillway or outlet structure, and is usually caused by foundation problems in the soil or rock below the structure in question. Cracks may also be considered as deterioration, but they are discussed separately because of their importance to structure stability. Concrete structures are often undermined by water seepage or piping, and eventually experience structural damage as the concrete settles into the underlying voids.

6.3.1 Concrete Spillways and Outlets

Cracks are commonly encountered defects for concrete spillways; cracks are less common in outlets, although they still occur. Cracks may be caused by foundation problems, water pressure, concrete expansion, freeze-thaw effects, poor concrete mix design, and chemical reactions. The discussion of cracks in this section applies to both spillways and outlets. The open, concrete spillway in Figure 6-7 has extensive cracking and deterioration and should be repaired.

Figure 6-7 Concrete spillway showing extensive cracking and general deterioration, most likely a result of freeze-thaw effects.

Cracks in the concrete may be structural or surface cracks. Surface cracks are generally less than a tenth of an inch wide and deep. These are often called hairline cracks and may consist of single, thin cracks, or cracks in a craze/map-like pattern. A small number of surface or shrinkage cracks is common and does not usually cause any problems. Surface cracks are commonly caused by freezing and thawing, poor design or construction practices, and alkali-aggregate reactivity. Large cracks present the greatest potential for safety concerns and usually develop as a result of structural problems. Large cracks will usually result in rapid deterioration of the spillway. Misalignment and displacement of spillway walls and chute slabs are often associated with large cracks. These cracks may be caused by uneven foundation settlement, foundation erosion, slab displacement, or excessive earth or water pressure. Large cracks will allow water to wash out the materials below or behind the concrete slab, causing erosion and leading to more cracks. Extensive cracking can cause the concrete slab to be severely displaced, dislodged, or washed away by the flow. When large cracks are

Figure 6-8 Concrete spillway with structure damage.

observed, the inspector should look for structure alignment and foundation problems.

Cracks provide openings in the concrete that permit further deterioration of the concrete. A concrete spillway may have to withstand considerable hydrostatic pressure from the reservoir and groundwater. Hydrostatic pressure acting along cracks through the concrete structure may exert dangerous uplift forces, possibly leading to lateral propagation of the cracks and uplifting, settlement, or sliding of a portion of the structure. A severely cracked concrete spillway should be examined by a qualified dam safety professional.

By definition, a crack is a separation of portions of a concrete structure into one or more major parts, and is usually the first sign of concrete distress. There are two general categories of cracking typically found on concrete structures: (1) **individual cracks**, and (2) **pervasive cracks**. A concrete structure may have one or a limited number of individual cracks that can be individually measured and documented during the visual inspection. Structural cracks are usually individual or a number of individual cracks. Often, numerous cracks may be visible within areas of a concrete surface, or the cracking may affect the entire surface. This condition is known as pervasive cracking. Pervasive cracking tends to have a number of typical appearances produced by specific causes. Pervasive cracking usually is a sign of some form of concrete deterioration.

When the concrete exhibits pervasive cracking and has extensively cracked surfaces, the primary focus of the visual inspection should be the location, nature, and extent of cracking rather than the dimensions of individual cracks. If individual cracking is observed, the location and dimensions should be recorded for each crack.

The inspector should determine if the cracking is an individual or limited number of individual cracks, or pervasive cracks. The American Concrete Institute (ACI) has developed standardized terms to describe the appearance of individual and pervasive cracks. After the inspector has classified the cracks as either individual or pervasive crack, he/she should then further describe the cracks using the ACI terminology.

6.3.1.1 Individual Cracks

ACI standardized terms to describe the appearance of individual cracks includes direction, width, and depth. These terms are listed on Table 6-2; it is recommended that the inspector use this terminology to describe individual cracks in concrete structures. The same terminology applies to concrete

Table 6-2
ACI Standardized Terminology for Individual Concrete Cracks

(1) Direction	**(2) Width**
Longitudinal	Fine: less than 0.5 mm
Transverse	Medium: between 0.5 and 2 mm
Vertical	Wide: over 2 mm
Diagonal	
Random	

(3) Depth (measure each crack)

Consistent with terminology used for cracking in embankment dams, some nomenclature for cracks in concrete dams differentiates cracks, on and parallel to the crest of a structure - termed longitudinal - from cracks on faces of the structure, which are designated as horizontal. ACI uses the term longitudinal to describe cracks in either location that are parallel to the crest. ACI 201.1, *Guide to Making a Condition Survey of Concrete in Service*, is a useful document that should be used if the inspector needs more information.

dams. This terminology describes the crack based on its orientation, or direction, width, and depth, as summarized on the table.

A crack in a concrete conduit through an embankment dam could allow reservoir water under pressure to enter and erode the embankment along the conduit. Cracks that cause leakage into the embankment or into the pipe from the reservoir should be immediately repaired. These cracks are usually structural cracks in the conduit walls and floor, caused by uneven settlement or foundation erosion.

Large cracks may be an indication of structural problems and are potential safety concerns. The location, width, length, and orientation of the crack(s) should be recorded during the visual inspection. Large cracks are often the result of serious problems under the concrete. The inspector should also determine if concrete around the crack has deteriorated or whether reinforcing bars are exposed. Spillway retaining walls or chute slabs may be displaced from their original position as a result of foundation settlement, or earth or water pressure. The inspector can sight carefully at the upstream or downstream end of the spillway near the wall to determine if it has been tipped inward or outward. Relative displacement or offset between adjacent sections of concrete can be readily identified at the joint. The horizontal and vertical displacement should be measured and recorded. If a fence line was constructed on top of the retaining wall, it can be used to help determine if the wall is distorted. Fences are usually erected in a straight line at the time of construction, therefore a curve or distortion of the fence line may indicate that the wall has deformed. The entire spillway chute should form a smooth surface. Measurement of relative movement between neighboring chute slabs at the joint will give a good indication of the slab displacement. Large cracks and associated problems are usually easy to see during a visual inspection. A clear description of crack patterns should be recorded and photos taken to help in understanding the nature of the displacement.

A large crack is often a structural crack and may require immediate repair. A large crack in a concrete spillway or discharge channel also could allow erosion of underlying material, resulting in loss of support and failure of the spillway. A badly cracked channel wall might fall when subjected to pressure from a large discharge. The inspector should always closely evaluate large cracks and determine their potential impact to the safety of the dam.

6.3.1.2 Pervasive Cracks

ACI uses three general classifications to describe extensive, or pervasive cracking of concrete surfaces based on the shape of the cracks: (1) pattern cracking, (2) D-cracking, and (3) checking. Therefore, pervasive cracking should be further classified based on these shape descriptions. Figure 6-9 illustrates the different forms of pattern cracking that may be found on concrete structures.

Pattern Cracking

Pattern cracking is a form of pervasive cracking that consists of openings on a concrete surface in the form of a pattern, and is caused by either shrinkage of concrete near the surface or a volumetric increase in concrete below the surface layer. Thermal stress, alkali-aggregate reaction, and freeze-thaw actions cause changes in the volume of concrete.

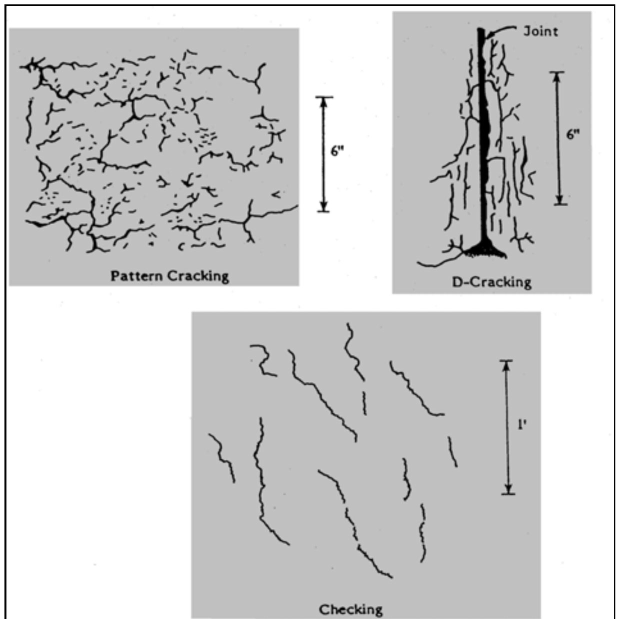


Figure 6-9 Different forms of pervasive cracking.

Cement hydration in mass concrete causes heat resulting in expansion. This, followed by differential cooling and shrinkage of the outer surface, is a major cause of thermal cracking. Reactions within massive concrete sections may continue to generate hydration heat for decades. Restraint by rigid foundations or old lifts of concrete is also a factor. Thermal cracks are deep, often extending through thin sections.

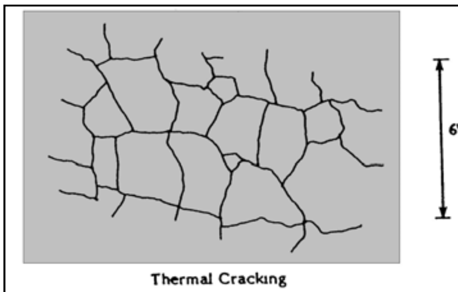


Figure 6-10 Illustration of thermal cracking.

The inspector should be especially alert for thermal cracking in the massive concrete monoliths of concrete structures or dams. A pattern of hairline cracks in an orthogonal, blocky "dried mud puddle" configuration inside of galleries, usually accompanied by considerable leakage, is a sign of thermal cracking. Another sign of thermal cracking is the presence of vertical cracks continuous through walls, ceilings, and floors of transverse galleries resulting from cooling of concrete and restraint near the foundation. If thermal cracking is suspected, installing temperature gages for temperature studies provides a means to collect relevant data.

If available, the mix designs for the dam structure should be reviewed. Failure to use low-strength concrete for the interior and high-strength concrete on the exterior of the structure may have promoted thermal cracking.

Construction records should be checked for a lack of such measures as use of thinner lifts, controlling concrete placement temperature, replacement of cement with pozzolan, and a reduced construction rate to deal with hydration heat.

Alkali-aggregate reaction can also cause pattern cracking. This condition is a reaction between soluble alkalis in the cement and silica in the aggregate and can cause abnormal expansion and cracking that may continue for many years. If the inspector observes pattern cracking in areas exposed to wet-dry cycles, the cause may be alkali-aggregate reaction. Alkali-aggregate reaction is described more fully in the following subchapter on deterioration.

Freeze-thaw action is another common cause of pattern cracking and D-cracking in northern and high elevation areas. Cracking increases geometrically with each freeze-thaw cycle. The freeze-thaw cycle starts when water enters pores, cracks, and joints in the concrete. When temperatures drop, water in the concrete freezes and expands, causing the concrete to crack. Water then enters the new cracks, and when temperatures drop again, the water freezes and expands, forcing the cracks to open wider. The pores and spaces in concrete must be nearly saturated for freeze-thaw action.

The inspector should examine areas of concrete exposed to moisture for damage from freeze-thaw action. Exposed horizontal surfaces such as slabs, and vertical walls near the water line are especially subject to freeze-thaw damage. Surfaces with a southern exposure can have accelerated damage due to daily freeze-thaw cycles. Use of entrained air helps protect concrete from freeze-thaw damage. Lack of entrained air in pre-1940 concrete elements, or an improper percent of entrained air, may have resulted in concrete that is vulnerable to damage.

D-Cracking

D-cracking is another form of pervasive cracking that consists of fine parallel cracks at close intervals, usually along joints or edges. This pattern of cracking is an early sign of damage from freeze-thaw action. Low-quality limestone aggregates are commonly the cause of D-cracking. D-cracking is commonly seen at the exposed corners of slabs and walls formed by joints.

Checking

Checking consists of the development of fine, pervasive cracks on the surface of concrete that show no evidence of movement, are shallow, and are closely spaced at irregular intervals. Cracks that display checking may be several feet long.

Checking is usually caused by expansion and contraction or shrinkage of the concrete surface with alternating wet-dry periods. Rapid drying of newly placed concrete may also result in checking of the concrete surface.

6.3.1.3 Hairline Cracks

Hairline cracks are surface cracks and are generally less than a tenth of an inch wide and deep. They may consist of single, thin cracks, or pervasive cracks in a craze/map-like pattern, as described above. A small number of surface or shrinkage cracks is common and does not usually cause any problems. Minor or hairline surface cracking can be caused by weathering, the quality of the concrete that was applied, freezing and thawing, poor construction practices, chemical reactivity, and other factors as described above under pervasive cracks.

Hairline cracks are usually harmless and pose no immediate threat to the stability of the spillway structure. This type of cracking should be noted and monitored on a routine basis for signs of additional deterioration. The location, orientation, length and width of the hairline cracks should be reported by the inspector.

The results of this minor cracking can be the eventual loss of concrete, which exposes reinforcing steel and accelerates deterioration. Generally, minor surface cracking does not affect the structural integrity and performance of the concrete structure.

Even if a crack itself does not present a serious threat, the mechanism causing the crack may threaten the structure. Cracking in concrete may be a visible indication of stress or movement which the concrete cannot accommodate. The underlying cause of cracking may pose an immediate threat to the dam and should be determined. Therefore, the inspector should try to determine the cause of any cracking that is present.

6.3.1.4 Structural Cracks

The inspector should be able to recognize cracks that may affect the safety of the dam; these cracks are commonly called **structural cracks**. A structural crack compromises the integrity of a concrete structure and therefore may pose a safety problem. In appearance, a structural crack may be:

Figure 6-11 Large structural cracks with vertical displacement.

- Diagonal or random with abrupt changes in direction
- Wide (greater than 0.25 in.), with a tendency to increase in width
- Adjacent to concrete that is noticeably displaced
- Occasionally narrow and diagonal, indicating inadequate design for shear stresses
- Long, single or multiple diagonal cracks with displacement and misalignment

Structural cracks usually result from movement of portions of a structure or overstressing. External stresses may be caused by extreme or differential loading conditions, foundation settlement, seismic activity, design or construction errors, or deficiencies in the concrete materials. Flaws in structure design may result in stresses too great for the concrete to withstand. Concrete mixtures with deficient strength or elastic properties may crack under design stresses. Poor construction techniques may also be responsible for deficiencies that promote cracking. Deep, wide cracking is usually due to stresses which are primarily caused by shrinkage, structural loads, or loss of foundation material.

Figure 6-12 Serious structural damage requires replacement of spillway.

Structural problems are indicated by cracking, exposure of reinforcing bars, large areas of broken-out concrete, misalignment at joints, undermining, and settlement in the structure. Rust stains that are noted on the concrete may indicate that internal corrosion and deterioration of reinforcement steel is occurring. Spillway floor slabs and upstream slope protection slabs should be checked for erosion of underlying base material otherwise known as undermining. Concrete walls and tower structures should be examined to determine if settlement and misalignment of construction joints has occurred. Cracks extending across concrete slabs which line open channel spillways or provide upstream slope wave protection can indicate a loss of foundation support resulting from settlement, piping, undermining, or erosion of foundation soils. Piping and erosion of foundation soils may be the result of inadequate under-drainage and/or cutoff walls.

Figure 6-13 This concrete spillway was completely destroyed as a result of foundation erosion.

Items to consider when evaluating a suspected structural crack are the concrete thickness, the size and location of the reinforcing steel, the type of foundation, and the drainage provision for the structure. Floor or wall movement, extensive cracking, improper alignments, settlement, joint displacement, and extensive undermining are signs of major structural problems. Drainage systems may be needed to relieve excessive water pressures under floors and behind walls. Because of their complex nature, major structural repairs require professional advice and design. Part 2 of the Indiana Dam Safety Inspection Manual describes repair operations in more detail. The particular method of repair will depend on the size of the job and the type of repair required.

Cracks through concrete surfaces exposed to flowing water may lead to the erosion or piping of embankment or foundation soils from around and/or under the concrete structure. In this case, the cracks are not the result of a problem but are the detrimental condition which leads to piping and erosion. Seepage at the discharge end of a spillway or outlet structure may indicate leakage of water through a crack. Proper under-drainage for open channel spillways with structural concrete floors is necessary to control this leakage. Flows from under-drain outlets and pressure relief holes should also be observed and measured. Cloudy flows may indicate that piping is occurring beneath or adjacent to the concrete structure. This could be detrimental to the foundation support.

The inspector should look for structural cracks at areas of stress concentrations, such as: corners of openings; contraction joints; areas of large temperature gradients, foundation and abutment material changes, slope changes, or direction changes relative to the section of the structure. Temperature variations between the air and reservoir water in cold weather can cause cracks extending from the structure crest down each face. Structural cracks often are wide, change widths with load changes or temperature cycles, or include significant leakage. The inspector should compare his/her observations with the drawings, photos, or sketches from past inspections, and be alert for new cracks and for changes that depart from past trends.

Concrete surfaces adjacent to contraction joints and subject to flowing water are of special concern, especially in chute slabs. The adjacent slabs must be flush, or the downstream slab should be slightly lower to prevent erosion or cavitation damage of the concrete and to prevent water from being directed into the joint during high velocity flow.

All weep holes should be checked for the accumulation of silt and granular deposits at their outlets. These deposits may obstruct flow or indicate loss of support material behind the concrete surfaces. Weep holes in the concrete are used to allow free drainage and relieve excessive hydrostatic pressures from building up underneath the structure. Excessive hydrostatic pressures underneath the concrete could cause it to heave or crack which increases the potential for accelerated deterioration and undermining. Periodic monitoring of the weep hole drains should be performed and documented on a regular and routine basis to ensure that they are functioning as designed.

Tapping concrete surfaces with a hammer or some other device will help locate voids if they are present as well as give an indication of the condition and soundness of the concrete.

Visual inspection of intake structures, trash racks, upstream conduits, and stilling basin concrete surfaces that are below the water surface is not readily feasible during a regularly scheduled inspection. Typically, stilling basins require the most regular monitoring and major maintenance because they are holding ponds for rock and debris, which can cause extensive damage to the concrete surfaces during the dissipation of flowing water. Therefore, special inspections of these features should be performed at least once every five years by either dewatering the structure or when operating conditions permit. Investigation of these features using experienced divers is also an alternative.

6.3.1.5 Reporting Cracks

The inspector should examine and report all types of cracks, using the ACI terminology described earlier. Therefore, the inspector will have to be able to identify and describe cracks to be able to effectively inspect concrete structures. Structural cracks are serious and should be carefully evaluated and documented.

Table 6-3
Description of Cracks

Individual Cracks	Pervasive Cracks
- Direction - Width - Depth	- Pattern Cracks - D-Cracks - Checking
Hairline Cracks	**Structural Cracks**
- Individual Cracks - Pervasive Cracks	- Individual Cracks are typical

If the problem associated with the cracks is serious and potentially affects the integrity of the dam or its appurtenant works, a crack survey may be warranted. A crack survey is an examination of a concrete structure for the purpose of locating, recording, and identifying cracks and of noting the relationship of the cracks with other signs of distress. A design drawing or inspection drawing is often used to record the location and extent of cracks in this type of survey. A grid system established with paint or chalk on a structure's surface can be used as an aid to determine crack locations.

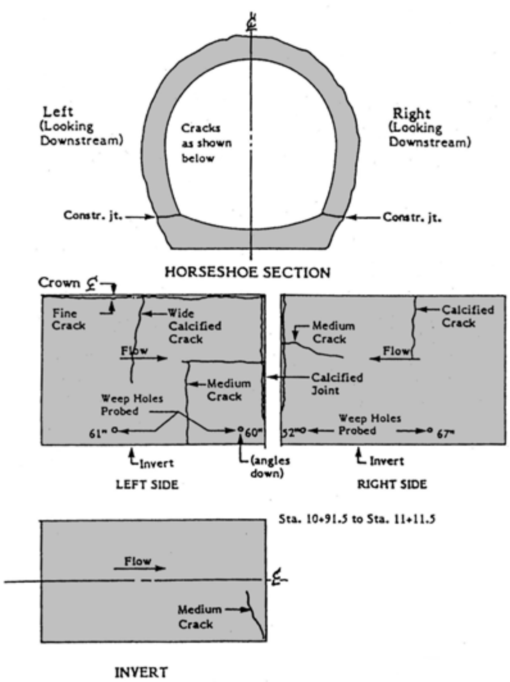


Figure 6-14 Sketch of cracking observed during an inspection.

A crack survey should identify characteristics of the cracks such as, length, width, direction, trend, depth, offset, and location. It should also describe the cracks based on the definitions presented above.

For monitoring purposes, measurement points should be marked, and the sharp edges of cracks should be protected with a thin coat of clear epoxy. This will prevent spalling or degrading of the edges which would give falsely high width measurements. The inspector should use a comparator, feeler gage, or a handheld illuminated microscope to measure the width. (A comparator is printed or inscribed with lines of various widths on a transparent background. The inspector places the comparator over a crack and matches crack width to a line. Two versions of comparators exist. One is a lighted magnifying glass with an eyepiece scribed with lines. The other is a clear plastic card printed with lines.)

Whenever feasible, external cracks should be correlated with internal cracks. Where repairs have been made to the concrete, crack surveys are difficult to perform and may be unreliable because cracks beneath the repairs may indicate deficiencies at greater depths. It is significant, however, to note whether new cracks have developed in the repaired concrete. Such cracks may indicate continuing structural problems.

Other conditions or deficiencies are often associated with cracking, such as leakage, deposits from leaching or other sources, and spalling of crack edges. These conditions should also be reported by the inspector.

The inspector should always look for seepage in or out of cracks. Water from seepage or leakage may compound the problem, leading to further degradation, including:

- The development of excessive hydrostatic pressures on some portions of the structure
- Attacking the concrete chemically
- Freeze-thaw damage to concrete
- Erosion or solution of the foundation material
- Leaching of the concrete

Chemical analysis of leakage water and deposits may be advisable if other problems begin to develop.

Sometimes the leakage source can be determined by simple measurements comparing leakage water temperature with ground water and reservoir temperatures. Dye tests are another means of identifying leakage sources. Approved dyes can be placed in the water upstream of the structure, in drill holes, or in other accessible locations. The location and time the dyes appear downstream can locate the sources and velocity of leakage.

The most common leakage measuring devices include a container and stopwatch, weir, flume, and flow meter. A container and a stopwatch may be used to measure the leakage from a crack if the water can be conveniently contained. It may be necessary to use a plate or other device to get the leakage to spring free from the concrete surface and into the container. Sometimes the seepage water may have to be collected or measured at a point downstream of the source to make it convenient to do so. It is not always easy to collect and measure water flow rate from seeps; the inspector may have to be creative to implement a collection and measurement procedure.

Movement between adjacent concrete surfaces or between concrete surfaces and the foundation can be measured with survey instruments, foundation baseplates, settlement sensors, inclinometers, extensometers, tiltmeters, plumblines, measurement points, calibrated crack monitors, joint meters, embedded strain meters, stress meters, and temperature gages. The inspector should note all instances when monitoring equipment reveals enlargement or other changes in a crack. Also, he/she should examine other instrumentation measurements for evidence of conditions that may have caused changes in the crack.

If cracking is observed during a visual inspection of a concrete spillway or outlet, the following actions should be taken:

- Photograph and record location, depth, length, width, and offset of the cracks.
- Note prominent cracks, cracking over large areas, and the trends for particular cracks.
- Look for structural damage, including misalignment, settlement, vertical and horizontal displacement.
- Look for any surrounding cracks.
- Classify and describe the cracks using the terminology defined above.
- If extensive new cracking is observed, consider initiating a crack survey to thoroughly document all cracks in the structure and their characteristics. Contact a qualified dam safety professional if there is uncertainty about the severity of cracking or if the following conditions are observed:

  - A major new crack
  - A crack(s) that has changed significantly since the last inspection
  - Cracks indicating movement that might be detrimental to the structure or to equipment operation
  - Significant leakage

- Look for evidence of seepage or saturated soils in or below the cracks. Also look for signs of foundation soil erosion. If there is an excessive amount of water, or water which cannot be handled by the drainage system is flowing through a crack, recommend repairs. Check with a concrete specialist to identify appropriate repair procedures.
- Determine if other dam structures, such as the embankment, could be affected by the cracking in the spillway.
- Closely monitor the cracks for changes.
- Try to determine the cause of the cracking; this can help identify effective corrective actions.
- Consult a qualified dam safety professional to determine the cause of the cracking if it is severe or gets progressively worse. Serious cracking or repair operations may require lowering the reservoir level.
- Recommend appropriate corrective action be taken to repair or to replace the damaged spillway areas. The recommended corrective actions should be consistent with the inspector’s training and experience.

If instrumentation has been installed to monitor serious cracks, the data may supply reasons for the cracking. Measurements of leakage and movement are particularly important for evaluating cracks, as well as for evaluating joints, which also are subject to leakage and movement.

Any recommendations the inspector may make for simple corrective actions should be reviewed by qualified dam safety professionals. Extensive corrective actions that may be taken in response to inspection findings include:

- For cracks that may be leaking but there is not a high hydrostatic head, treatment may consist of grouting the crack by injecting either an elastomeric filler (if crack movement is anticipated) or a rigid epoxy mortar.
- For cracks where leakage is accompanied by high hydrostatic pressure, installation of a drainage system may be necessary.
- If structural analysis shows a crack has affected the structure's stability, post-tensioning between components of the structure or between the structure and foundation rock or anchors may be required.
- Collapsed slabs and wall may need complete replacement and foundation repair.
- Concrete conduits may need to be replaced if the damage is severe. Conduit linings may also be applicable.

Repair materials that may be used include epoxy grout, methacrylates, polymerized concrete or mortar, fiber-reinforced concrete, and very low water-cement ratio concrete. Part 2 of the Indiana Dam Safety Inspection Manual provides additional details for the maintenance and repair of concrete structures.

6.3.2 Earthen Spillways

Figure 6-15 Earthen spillways located on fill are not recommended and should be closely monitored.

Earthen spillways may be affected by the same type of cracking problems encountered on embankments (Part 3, Chapter 5). However, cracks observed in earthen spillways are usually not as critical as those on embankments since the spillways are typically on insitu ground. Desiccation cracks in an earthen spillway or channel are usually not regarded as a functional problem, but should be noted on the inspection report nonetheless. Deep cracks that are wider than ½ inch may be signs of slope stability issues, including sloughing or sliding. The side walls of earthen spillways are usually more vulnerable to stability problems than the floor since they are usually steeper and may contain groundwater seeps. Seepage from the reservoir or insitu ground may saturate spillway soils, making conditions for a slide favorable. Cracks that are deep and relatively wide (greater than ½ inch) may be an indication that a slide is developing in the soil. Cracking should be considered as a serious problem if it is the beginning of a slide. Slides are structural problems that can reduce the spillway capacity by obstructing the flow path, or can lower the elevation of the spillway control section, depending on the location of the slide. The inspector should monitor the condition frequently for sloughing, bulging, or the formation of scarps.

If cracking or slides are observed during a visual inspection of an earthen spillway, the following actions should be taken:

- Photograph and record location, depth, length, width, and offset of the cracks or scarps, if present.
- Make sure that the spillway control section and discharge channel are on insitu ground. If not, note this as a serious concern.
- Look for any surrounding cracks.
- If a bulge is present, closely inspect the area above the bulge for cracking or scarps which indicate that a slide is the cause. Probe the bulge to determine if material is excessively moist or soft. Excessive moisture or softness usually indicates that a slide is the cause.
- Look for evidence of seepage or saturated soils in or below the cracks or slide. Probe the entire area to determine the condition of the surface material.
- Determine if other dam structures, such as the embankment, could be affected by the cracking or slide in the spillway.
- Closely monitor the cracks or slide for changes.
- Consult a qualified dam safety professional to determine the cause of the cracking or slide if it is severe or gets progressively worse. Serious cracking, slides or repair operations may require lowering the reservoir level. In most instances, deep-seated slides near or at the control section will require the lowering or draining of the reservoir to prevent the possible breaching of the dam.
- Recommend appropriate corrective action be taken to repair or to replace the damaged spillway areas.

The inspector should consider the worst case scenarios when evaluating earthen spillways. This typically means a condition in which the spillway is flowing at maximum design levels. The inspector should consider the frequency, duration, depth, and velocities of potential spillway flows.

6.4 INADEQUATE EROSION PROTECTION

When a large storm occurs, the spillway system is expected to carry a large amount of water for many hours. Severe erosion damage or complete wash-out could result if the spillway lacks the ability to resist erosion. If the spillway is excavated in a hard rock formation or lined with concrete, erosion is usually not a problem. But, if the spillway is excavated in sandy soil, deteriorated rock, clay, or silt deposits, erosion protection is very important. Generally, resistance to erosion can be increased if the spillway channel has a mild slope, or if it is covered with a layer of grass or riprap with bedding material.

Erosion at a spillway outlet, whether it be a pipe or overflow spillway, is one of the most common erosion problems encountered. Severe erosion or undermining of the outlet can displace sections of pipe, cause slides in the downstream slope of the dam as erosion continues, and eventually lead to complete failure of the spillway or dam. Water must be conveyed safely from the reservoir to a point downstream of the dam without endangering the spillway or embankment. Often the spillway outlet is adequately protected for normal flow conditions, but not for extreme flows. It is easy to underestimate the energy and force of flowing water and/or overestimate the resistance of the outlet material (earth, rock, concrete, etc). The required level of protection is hard to establish by visual inspection, but can usually be determined by hydraulic calculations performed by a professional engineer. Missing rocks in a riprap lining can be considered as a breach in the protective cover, and this should be repaired as soon as possible. The inspector should look for signs of erosion and inadequate erosion protection at the outlet of all spillways and outlets.

Figure 6-16 Poor spillway lining.

Figure 6-17 Riprap lining was completely washed away during a significant storm event, exposing the geotextile filter.

Stilling basins are often used at outlets to absorb the discharge energy. Stilling basins consist of a lined depression at the outlet of the spillway or outlet conduit. Stilling basins are commonly lined with riprap and a suitable bedding/filter material. Displaced riprap in stilling basins can result in additional scouring in the basin which creates a deeper or larger depression and sedimentation downstream. If the scouring is serious, it can erode the toe of embankment dams, or undermine the outlet of spillways and outlets. The inspector should look for signs of rock displacement and scouring, particularly at the downstream end of the basin, and sedimentation in the receiving channel.

Vegetative lining (grass) is often used in emergency spillway discharge channels. Grass linings can protect soil on relatively flat slopes and low discharge velocities. Typically, grass linings are adequate for water velocities of 5 ft/s or less. Bare spots,

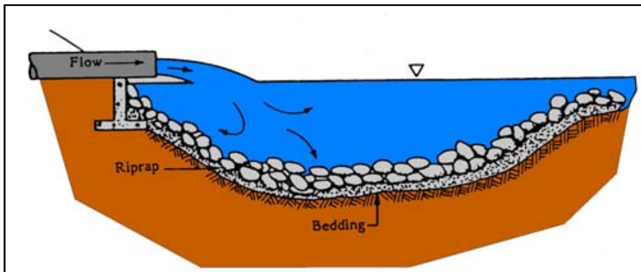


Figure 6-18 Typical rock-lined stilling basin at spillway outlet.

Figure 6-19 Grass lined outlet channel that was not designed for the flows it experienced, resulting in severe erosion.

or areas where the grass is sparse, are susceptible to erosion problems and should be carefully inspected for erosion rills and gullies. Wide grass-lined spillways should be examined for erosion gullies and rills from stormwater runoff within the spillway.

Runoff will often concentrate in specific areas in the spillway and erode the surface soils. Although this is usually not a problem, it should be corrected before the erosion gullies get too deep. Shallow erosion rills should be monitored for additional damage from rainfall. Erosion rills and gullies generally will get worse with time. The inspector should determine the cause for the formation of the erosion features and recommend repairs that correct this problem. Often it is the result of uneven grading practices that tend to make the runoff flow to one spot or route in the spillway.

Many new synthetic lining materials are also available that will protect soil spillways from erosion at much higher velocities than grass. The degree of protection of these materials varies with the manufacturer and type of material. These materials are generally installed as blankets. These materials should be inspected for undermining, tearing, displacement, and exposure to the sun (will deteriorate).

Figure 6-20 Severe gully erosion.

Reservoir outlet works usually discharge into the spillway terminal structures, and the discharge from these structures may be intermittent. When the outlets have a separate outfall point and terminal structure, they should also be examined in the same manner as the spillway structures.

During the visual inspection, the inspector should look for inadequate erosion protection:

- Make sure that the grass, riprap, or other erosion protection is adequate to prevent erosion. Bald areas or areas where the surface protection is sparse are more susceptible to surface runoff and flowing water problems.

- Look for gullies, ruts, or other signs of surface runoff erosion. Be sure to check the low points at the spillway outfall, and areas where stormwater runoff can concentrate.
- Check for any unique problems, such as livestock or recreational vehicles that may be contributing to erosion.

If inadequate spillway protection is observed, the inspector should:

- Record the findings and photograph the area.
- Determine the cause and extent to which the spillway has been damaged (i.e., spillway foundation or soil material has been removed).
- Recommend that corrective action be taken to repair or to replace the inadequate spillway protection.
- Consult a qualified dam safety professional if necessary.

If erosion is observed, the inspector should:

- Record his/her findings and photograph the area.
- Determine the extent, severity, and cause of the damage.
- Recommend that corrective action is taken to repair the areas damaged by surface runoff and that measures are taken to prevent more serious problems.
- If spillway control sections need repaired, or extensive embankment excavation is required, the reservoir level may need to be lowered.

6.5 DETERIORATION

6.5.1 Overview

Figure 6-21 General deterioration of a concrete spillway as a result of multiple causes.

Deterioration is any adverse change on the surface or in the body of spillways and outlets that causes the structure to separate, break apart, or lose strength. A spillway cannot be expected to perform properly if it is deteriorated. The term, deterioration, is most commonly used in reference to the general condition of a construction material such as concrete, rock, metal, plastic, or wood and can result in the complete destruction of a material. The amount of deterioration which has occurred in a material is gaged with respect to its original condition. Deterioration of a material is normally due to the forces of nature such as wetting and drying, freezing and thawing, oxidation, decay, ultraviolet light, and erosive forces of wind and water. Activities of humans can also contribute to deterioration by altering the chemical composition of water through application of chemicals on or near a dam, and by virtue of the use of the dam (mine tailings, waste storage or retention, and product storage). A subjective evaluation of the extent and possible effects of deterioration should be made.

Sometimes deterioration will be complete enough to result in other detrimental conditions. These include riprap deterioration because of bedding erosion, structural failures of concrete because of reinforcing corrosion, erosion and piping due to metal pipe corrosion, and plastic pipe cracking because of ultraviolet light deterioration.

Outward signs of deterioration include conditions such as collapse of side slopes, weathering of material, disintegration of riprap, breakdown of concrete lining, erosion of the concrete spillways, sloughing of discharge channels, excessive siltation of a stilling basin or discharge channel, and loss of protective grass cover, etc. These conditions can lead to flows under and around the protective material which can cause severe erosion. Remedial actions should be taken as soon as any sign of deterioration has been detected, even during storm flows. Cracks are a form of deterioration; cracking was discussed in detail earlier.

The inspector should attempt to understand as fully as possible why deterioration has occurred. Understanding the cause may reveal a solution, or measures that would prevent further damage. A large concrete spall adjacent to a joint, especially on a spillway slab, will require careful examination of the joint. As an example, loss of joint filler and replacement with sand or sediment can make joints too rigid to expand, causing spalling. Cleaning debris from joints and application of new joint filler might prevent further spalling.

6.5.2 Concrete Structures

6.5.2.1 Overview

Most concrete structures in Indiana experience some form of deterioration due to the severe nature of the climate and the dam environment. Typical types of concrete deterioration are summarized on Table 6-4. Most forms of concrete deterioration develop over a relatively long period of time with visual warning signs. So there is usually sufficient time to repair the structure before total failure occurs.

Table 6-4
Common Types of Concrete Deterioration

- Disintegration
- Scaling
- Spalling
- Popouts
- Pitting
- Efflorescence
- Drummy concrete
- Faulty concrete mixes
- Chemical attack
    - Sulfate attack
    - Acid attack
    - Alkali-aggregate reaction
- Metal corrosion
- Erosion
- Joint deterioration
- Cavitation
- Surface defects

Deterioration of concrete may be caused by many factors, including weathering, mechanical impacts, internal pressure, drying shrinkage, thermal stress, chemical action, leaching by water seepage, poor concrete mixes, poor concrete design, and freeze-thaw action. The use of excessive mix water is the single most common cause of damage to concrete. It may be difficult to isolate the specific cause for concrete deterioration. If the inspector is not sure, he/she should obtain professional help, or define the potential cause within a range of two or three possible causes. Sometimes, more than one mechanism may be involved. For example, cracking from thermal stress or drying shrinkage may lead to freeze-thaw action or leaching by water seepage.


Figure 6-22 Deterioration (cracking and spalling) of a concrete spillway from weathering and freeze-thaw effects.

Deterioration can weaken the design strength of a concrete structure and cause it to fail. Concrete deterioration may cause leakage and associated water pressures to increase. Deterioration may also result in distortion of a structure, causing binding of mechanical features such as gates which must operate to ensure the safety of a dam. The inspector should look for damage to other equipment and structures as a result of the concrete deterioration.

Deterioration may be isolated to some concrete elements, or may be due to a serious flaw in all of the concrete used in a structure. When stresses such as hydrostatic pressure or earth loads exceed the strength of a weakened element or structure, the dam or appurtenances may fail catastrophically. Some forms of deterioration may affect the safety of the structure immediately or in the near future. Seepage through a weakened concrete structure is a serious problem and needs immediate attention. The inspector should examine all concrete surfaces for seepage, and record any findings.

If a poor concrete mix is a possible cause for deterioration, the inspector should examine construction records for information about the concrete. Poor concrete mix design generally involves larger areas of the structure.

Many times concrete that is cast around corrugated spillway conduits creates problems due to differential expansion and contraction. The two different materials expand and contract at different rates which may result in cracks in the concrete. Another problem created by casting concrete around corrugated pipes is the potential lack of adhesion between the concrete and pipe surfaces, resulting in seepage along the pipe. The inspector should carefully examine areas where pipes and conduits are connected to other structures for signs of deterioration and seepage.


Figure 6-23 Concrete is deteriorating where these metal pipes enter a spillway riser as a result of differential expansion rates.

The inspector also should look for failure of repairs. Corrective action for concrete deterioration often includes removal of the deteriorated concrete and replacement with superior concrete or another repair material. Shallow repairs with epoxy materials may fail with large drops in air temperatures. Patched areas tend to shrink and crumble, and often the patch material does not bond well to the original surface.

6.5.2.2 Types of Deterioration

The inspector can use the following terms to describe concrete deterioration. Many of the terms are interrelated, with one type of deterioration producing one or more other types. The use of common terminology will help reviewers to better understand the defects and problems. ACI 116, Cement and Concrete Terminology, is a good source of information to use to describe concrete deterioration.

Figure 6-24 Severe disintegration of a concrete structure caused by poor concrete mix and weathering.

Disintegration is the crumbling or deterioration of concrete into small particles. Disintegration may result in possible failure of a concrete element or structure. Disintegration is one of the most serious forms of concrete deterioration. Disintegration can be a result of many causes such as freezing and thawing, chemical attack, and poor construction practices. All exposed concrete is subject to freeze-thaw, but the concrete's resistance to weathering is determined by the concrete mix and the age of the concrete. Concrete with the proper amounts of air, water, and cement, and a properly sized aggregate, will be much more durable. In addition, proper drainage is essential in preventing freeze-thaw damage. When critically saturated concrete (when 90% of the pore space in the concrete is filled with water) is exposed to freezing temperatures, the water in the pore spaces within the concrete freezes and expands, damaging the concrete. Repeated cycles of freezing and thawing will result in surface scaling and can lead to disintegration of the concrete. Hydraulic structures are especially susceptible to freeze-thaw damage since they are more likely to be critically saturated. Older structures (pre-1940) are also more susceptible to freeze-thaw damage since the concrete probably was not air entrained. In addition, acidic substances in the surrounding soil and water can cause disintegration of the concrete surface due to a reaction between the acid and the hydrated cement. The inspector should record visible signs of deterioration and try to determine the cause while at the site.

Figure 6-25 Concrete riser is spalling, exposing rebar and experiencing loss of concrete.

Large areas of crumbling (rotten) concrete, areas of deterioration which are more than about 3 to 4 inches deep (depending on the wall/slab thickness), and exposed rebar indicate serious concrete deterioration. If not repaired, this type of concrete deterioration may lead to structural instability of the concrete structure. A registered professional engineer should prepare plans and specifications for repair of serious concrete deterioration.

Scaling is the flaking or peeling away of the concrete or mortar surface. Scaling also results in susceptibility to further deterioration of the structure. Scaling is a milder form of disintegration.

Spalling is the loss of larger pieces of concrete (usually flakes or wedge-shaped pieces) from a surface, often at edges, caused by a sudden impact, external pressure, weathering, internal pressure (e.g., corroded rebar near the surface), expansion within the concrete mass, or fires built on or against structures. It often occurs in concrete on exposed surfaces at corners or at joints. Concrete spalling could be the result freeze-thaw action, a repair which has deteriorated, or stresses on a concrete structure which exceed the design. In spillways or outlets, it may be due to the impact of rocks or other debris against the flow surface. Joint spalling is usually due to erosion, weathering and ice damage but can also be due to structure movement. Other causes include reinforcing deterioration, chemical reactivity of aggregates, and vandalism. When observed, the particular structure should be checked for additional deterioration, displacements, and structural damage.

Figure 6-26 Side wall of spillway is spalling.

Spalling usually affects only the surface of the structure, so it is not ordinarily considered dangerous. However, if allowed to continue, spalling will cause structural damage, particularly if the structure is of thin cross section. Spalling often results in exposed reinforcing, leakage paths opened around embedded waterstops at joints, offsets on flow surfaces, and development of points of structural weakness. Repair is necessary when reinforcing becomes exposed to the elements. The method of repair of spalled areas depends upon the depth of the deterioration. Repair should be considered temporary unless seepage through the structure can be halted. However, if a spall is large and causes structural damage, a registered professional engineer should prepare plans and specifications to repair the spalling.

Popouts are a form of small scale spalling, and occur when a small portion of the concrete surface breaks away due to internal pressure. Popouts are usually formed as the water in saturated coarse aggregate particles near the surface freezes, expands, and pushes off the top of the aggregate and surrounding mortar to create a shallow conical depression. Popouts are typically not a structural problem, but they do make the structure susceptible to further deterioration.

Pitting is the development of relatively small cavities in the concrete surface caused by localized disintegration. Pitting usually results in susceptibility to further deterioration of the structure. It may be caused by a number of reasons, including weathering, mechanical damage, localized chemical attack, etc.

Efflorescence is the leaching of calcium compounds from within the concrete and deposition on the surface due to water leaking through joints, cracks, or the concrete itself. It appears as a white, crystallized substance on the concrete surface. The seepage water dissolves soluble calcium hydroxide from cement within the concrete and carries it to the exposed face of the concrete. As water evaporates from the concrete surface, calcium hydroxide is deposited. These deposits react with carbon dioxide in the air to form calcium carbonate or the hard white deposits normally observed. The problem with water seepage is that as calcium hydroxide is leached from the concrete around the joint or crack, the opening widens permitting increased seepage. Widening of joints and increased seepage can lead to increased rates of deterioration and eventual loss of concrete strength.

Efflorescence in itself is not a problem except for the obvious undesirable effect on the concrete appearance. The amount of efflorescence and any increases in this amount over time should be visually evaluated to determine the potential for seepage to affect the integrity of the particular concrete structure.

Efflorescence is usually located near hairline cracks or thin cracks on spillway sidewalls. Efflorescence is usually accompanied by seepage. The seepage can make the concrete more susceptible to freeze-thaw action. In some cases, openings may be sealed against additional leakage by deposits. The deposits may even stop up drain holes and other leakage control features. Efflorescence should be monitored because it can indicate the amount of seepage finding its way through thin cracks in the concrete and can signal areas where problems could develop, such as inadequate drainage behind the concrete or concrete deterioration.

Drummy concrete is concrete with a void, separation, or other weakness beneath the surface, detected by a hollow sound when struck with a hammer, bonker, or other steel tool. Drummy concrete may result in diminished strength of concrete and susceptibility to further deterioration.

Faulty concrete mixes usually result from improperly graded aggregates, improper cement to water ratio, lack of or improper percent of entrained air, inadequate mixing, placing, or curing procedures or equipment, or improper use of additives. A faulty concrete may have a lack of strength, or may be susceptible to deterioration.

Chemical sulfate attack is a reaction between sulfates (calcium aluminate compounds) in soil and ground water with concrete. This type of deterioration may be caused by the use of pre-1930 mix designs that did not consider sulfate attack. The presence of sulfates in local soil or ground water may also be the cause. Sulfate may be derived from natural sources, manufacturing plant wastes, or agricultural runoff contaminating the reservoir water. The concrete usually appears light in color and falls apart easily when struck with a hammer. Other signs of chemical sulfate attack include cracking, spalling, scaling, stains, or total disintegration of the structure or portions of the structure. Type V Portland cement is highly resistant to sulfate attack.

Chemical acid attack is the action of acidic water on calcium hydroxide found in hydrated Portland cement, limestone, or dolomitic aggregates. Acidic water in the reservoir may originate from sewage discharges, coal mine drainage, cinder storage piles, atmospheric gases from nearby industry, industrial wastes, or severe acid rain. Chemical acid attack often leaches away acid-soluble compounds in the concrete, potentially resulting in complete removal of the concrete surface, or a color change of the structure surface. Corrosion and weakening of the reinforcing may also occur, resulting in overstressing of adjacent concrete, which may crack or spall.

Table 6-5

Early Indicators of Alkali-Aggregate Reaction

- Pattern cracking, usually in areas exposed to wet-dry cycles, such as:
  - Parapets
  - Piers
  - Top of a dam
- Efflorescence
- Incrustation
- White rings around aggregate particles
- Gel-like substance exuded at:
  - Cracks
  - Pores
  - Openings

Signs of Severe Alkali-Aggregate Reaction

- Disbonding of blocks at lift lines
- Binding of gates
- Severe cracking
- Loss of strength and ultimate failure of the structure
- Swelling

Alkali-aggregate reaction results from a chemical reaction between soluble alkali present in cements and certain forms of silica present in some aggregates. The use of marine sediments as aggregates, or shale from river gravels containing cherts often causes alkali-aggregate reactions. This chemical reaction produces byproducts in the form of silica gels which cause expansion and loss of strength within the concrete. Alkali reaction is characterized by certain observable conditions, such as, cracking, usually of random pattern on a fairly large scale, and by excessive internal and overall expansion. Additional indications are a gelatinous exudation and whitish amorphous deposit on the surface, and lifeless, chalky appearance of the freshly fractured concrete. The reaction takes place in the presence of water. Surfaces exposed to the elements or dampened as a result of through dam seepage will demonstrate the most rapid deterioration. Once suspected, the condition can be confirmed by a series of

Figure 6-27 Rebar exposed from spalling is rusting.

tests performed on cores drilled from the dam. Although the process of deterioration is gradual, alkali-aggregate reaction cannot be economically corrected by any means now known. Continued deterioration often requires total replacement of the structure. Deterioration of concrete from alkali-aggregate reaction may cause abnormal expansion and cracking that may continue for many years. Low alkali Portland cement and fly ash pozzolan can be used in new concrete to eliminate or greatly reduce the deterioration of reactive aggregates.

Metal corrosion is the formation of iron oxide, or rust, when water (especially salt water) reaches steel in the concrete. It may also be corrosion of aluminum, if used, when water reaches aluminum embedded in or on the concrete. It is often caused by the use of deicing salts on bridge decks and similar structures that can cause corrosion without initial deterioration of concrete. Corrosion typically results in an increase in volume of the reinforcing metal that causes cracking and spalling of overlying concrete (mostly affecting thin structures). Typically, the bond is broken between the steel (or aluminum) and concrete, destroying the structural strength. Visible signs of metal corrosion include straight, uniform crack lines above reinforcing, rust stains on the surface, spalling, exposed reinforcing, and deterioration of concrete adjacent to unprotected aluminum fish ladders, hydraulic pumps, gates, and guardrails.

Figure 6-28 Erosion of concrete on top of riser.

Erosion of concrete is caused by fast-moving water containing abrasive material such as sand and gravel, debris, and ice. Ballmilling is a form of erosion which is the grinding away of a surface, usually in a circular pattern, especially in stilling basins. Erosion results in the wearing away of softer aggregates, or of the matrix material around the aggregates. The inspector should also look for abrasion erosion at points of abrupt change in flow channels or at corners, and the loss of concrete from the surface. Erosion in its worst form may result in severe destruction of concrete.

Erosion due to abrasion results in a worn concrete surface, with polished-looking aggregate. It is caused by the rubbing and grinding of sand and gravel or other debris on the concrete surface of a spillway channel, conduit, or stilling basin. Minor erosion is not a problem but severe erosion can jeopardize the structural integrity of the concrete.

Erosion due to cavitation results in a rough pitted concrete surface. Cavitation is a process in which sub atmospheric pressures, turbulent flow and impact energy are created and will damage the concrete. If the shape of the upper curve on the ogee spillway is not designed close to its ideal shape, cavitation may occur just below the upper curve, causing erosion. If the concrete becomes severely pitted, it could lead to structural damage or failure of the structure.

Joint Deterioration - Spillway retaining walls and chute slabs are normally constructed in sections. Between adjoining sections, gaps or joints must be tightly sealed with flexible materials such as tar, epoxies, or other chemical compounds. Sometimes rubber or plastic diaphragm or copper foil is used to seal the joint watertight. During the visual inspection, note the location, length, and depth of any missing sealant. Also, probe the open gap and determine if soil behind the wall or below the slab has been removed by the erosive action of water.

Cavitation, a form of erosion, is the result of the formation of excessive negative air pressures in hydraulic structures. This condition is often caused by offsets or irregularities that produce turbulence. The results are usually pitting and spalling of the flow surfaces. Cavitation may be difficult to identify since it may be similar to other types of deterioration such as abrasion or corrosion of concrete, rock, and metal surfaces. Cavitation is not normally a problem where hydraulic heads are less than 25 feet. If identified, the hydrologic history is important to determine what event may have caused the damage and to evaluate the potential for additional cavitation to occur. Severe cavitation can produce extreme vibrations and erosion which may lead to structural damage and failure. Air vents to flow passages are often used to prevent cavitation; the vents should be examined visually or by pouring water into them to ensure that they are not obstructed.

Cavitation typically occurs downstream of gates and valves, and on steep spillway chutes, tunnels, or conduits. Cavitation creates the potential danger of rapid failure of a spillway or outlet works and that may result in subsequent failure of the dam during large flows.

Table 6-6
Common Surface Defects on Concrete Structures

• **Honeycomb:**	Voids in spaces between coarse aggregate particles. Cause - Poor construction practices: segregation due to improper placement or inadequate vibration.
• **Stratification:**	Separation into horizontal layers, with smaller material concentrated near the top. Possible results include nonuniform strength, weak areas, and disbonding of lifts. Cause - Overly wet or over-vibrated concrete, poor interlayer consolidation (vibration) or cold joints in placement.
• **Form Slippage:**	Slightly offset blocks, uneven joints and surfaces. Cause - Form movement during placement and vibration.
• **Stains:**	Discoloration. Cause - Deposits from runoff water, corrosion of exterior steel, spilled construction materials, or curing water with staining qualities.
• **Impact Damage:**	Marred or spalled surfaces. Cause - Blows from moving trucks, boats, cranes, or debris.

Surface Defects are other concrete deficiencies that may not be progressive in nature; that is, they do not necessarily become more extensive with time. Surface defects are usually shallow and do not normally present an immediate threat to the structure. However, they may make the concrete more susceptible to more significant deterioration.

Surface defects may include:

- Shallow deficiencies in the surface of the concrete

- Textural defects resulting from improper construction techniques
- Localized damage to the concrete surface

Concrete structures often show signs of some form of deterioration described above. Spillway entrance floors and walls may exhibit lost lining, scour, and undermining of the structure. The spillway control section floor may suffer from broken slabs, undermining of the structure and exposing the foundation, cracking and spalling, exposed reinforcing, pitting, and scour. Typical causes of these problems include initial construction with poor concrete, high erosive forces, and unbalanced hydraulic pressure against the slab.

The control section pier, walls, and overflow crest may exhibit signs of cracking, spalling, pitting, scour, exposed aggregate, and exposed reinforcing. These deficiencies are commonly the result of poor concrete mixes, chemical attack, erosion, alkali-aggregate reaction, and cavitation.

Figure 6-29 Erosion of foundation soil caused this concrete section to fail.

The discharge channel may exhibit rough patches, loss of concrete, foundation erosion, and exposed reinforcing. These conditions are caused by cavitation due to rough surfaces or irregularities, and erosion from carried debris. Foundation erosion is caused by seepage under the structure.

Common problems in the stilling basin and submerged roller bucket include scour holes more than 6 inches deep in the floor, loss of floor slabs, exposed and damaged reinforcing, and boulders in the basin. These problems are most often caused by inadequate hydraulic jump formation, and gravel or boulders rolling into the basin or bucket.

Non-submerged flip buckets may have visible scour holes (over 12 inches in diameter), blocks of broken concrete, and exposed reinforcing. The usual cause of these conditions includes heavy debris not swept out of bucket during operation.

Chute blocks or baffle blocks may develop damaged or displaced blocks, and exposed reinforcing caused by cavitation or large rocks or other hard debris in the basin or bucket.

Concrete outlet works usually consist of concrete conduits. These structures may suffer from pattern cracking, pitting, and spalling. The most common cause of this damage is from chemical attack, erosion, cavitation, or deformation due to high loads from earth embankments.

6.5.2.3 Reporting Concrete Deterioration

Condition surveys may be required to help evaluate concrete deterioration. Condition surveys are detailed engineering studies of concrete conditions that include reviews of engineering data, field investigation, and laboratory testing. If a condition survey was performed on a dam or its appurtenant structures, the survey should provide a basis for assessing the concrete deficiencies that may be encountered.

Surface mapping involves documenting concrete defects in a systematic manner. All types of concrete deterioration should be included. Surface mapping generally consists of developing a detailed record of the cracks on paper or on film so that future changes can be monitored. The mapping can be accomplished using detailed drawings, photographs, or videotape to record the current features and deficiencies. When photographs are used, a ruler or familiar object should be included to indicate scale. A grid is sometimes used to overlay a section of a drawing so the location of cracks and other defects can be shown easily.

If differential movement at joints or stress concentrations could have been responsible for damage, the inspector should review Instrumentation or measurement data for evidence of these conditions, or recommend that additional instrumentation be Installed to monitor the affected area.

If deterioration is observed during a visual inspection of a concrete spillway or outlet, the inspector should take the following actions:

- Photograph and record location, type, and extent of the deterioration. Note prominent features, and whether cracking is also present.
- Look for structural damage, including misalignment, settlement, vertical and horizontal displacement.
- Look for any surrounding damage to structures or foundation.
- Classify and describe the deterioration using the terminology defined earlier.
- If deterioration is extensive, consider initiating a condition survey or surface mapping to thoroughly document all problems in the structure and their characteristics. Contact a qualified dam safety professional if there is uncertainty about the severity of deterioration.
- Look for evidence of seepage or saturated soils in or below the structures. Also look for sign of foundation soil erosion. If there is an excessive amount of water, or water which cannot be handled by the drainage system is flowing through a crack, recommend repairs. Check with a concrete specialist to identify appropriate repair procedures.
- Determine if other dam structures, such as the embankment, could be affected by the deterioration in the spillway or outlet.
- Closely monitor the problems for changes.
- Try to determine the cause of the deterioration; this can help identify effective corrective actions.
- Consult a qualified dam safety professional to determine the cause of the

problem if it is severe or gets progressively worse. Serious deterioration or repair operations may require lowering the reservoir level.

- Recommend appropriate corrective action be taken to repair or to replace the damaged spillway or outlet areas. The recommended corrective actions should be consistent with the inspector's training and experience.

6.5.3 Metal Structures and Materials

A number of metal structures serve functions in dams and appurtenances. These structures may include metal gates and valves, conduits, cranes and hoists, and operating and access bridges. Some of these structures must maintain their operability to ensure the safety of the dam. Metal structures often serve as part of the outlet works that controls reservoir levels and releases excess flows, and so are especially crucial to dam safety. The failure of metal structures could form obstructions that would endanger the dam.

Figure 6-30 Soil erosion under this metal spillway caused the outlet end to settle, resulting in the inlet end tilting upward.

Figure 6-31 This corrugated spillway pipe rusted through, allowing seepage to enter the pipe.

Corrugated metal pipes that are used as spillway structures can have other serious problems besides corrosion. These problems are usually associated with installation practices, and include foundation or backfill erosion, and pipe buckling and crushing. These problems are usually caused by poor compaction in the haunching zone, poor compaction of backfill material beside and over the pipe, and heavy equipment traffic over the pipe. Because of these problems, corrugated metal pipes are not recommended for initial placement, upgrades, or replacements in any dam.

Metal suffers more damage from corrosion than from any other deficiency. Most metal deficiencies are types of corrosion, are related to corrosion, or eventually will involve corrosion. Coatings prevent or delay corrosion in metal. Failure of a coating, therefore, may result in failure of the metal structure due to corrosion. Corrosion is an electrochemical reaction and has been defined by the National Association of Corrosion Engineers as "the deterioration of a material, usually a metal, by reaction with its environment." The inspector should be able to recognize the types and hazards of metal corrosion, and distinguish hazardous metal corrosion from corrosion that is just a maintenance problem.

Destruction of metal parts obviously occurs by processes other than corrosion (e.g., abrasion, fatigue); however, these processes are often accompanied by corrosion of varying intensity. Corrosion may be widespread over the surface of a structure resulting in relatively uniform loss of metal, or it may be highly localized, resulting in pitting of the surface and possible penetration of the metal. Either form may be destructive, depending upon the operating requirements of the structure.

6.5.3.1 Corrosion

Corrosion is a common problem of pipe spillways and other conduits made of metal. Exposure to moisture, acid conditions, or salt will accelerate the corrosion process. Pipes made of non-corrosive materials such as concrete or plastic should be used in new dam construction, or in dam rehabilitation.

Corrosion of any metal component should be identified since it can weaken metal parts, decrease wall thicknesses, and hinder operation of mechanical equipment. This identification should cover mechanical equipment, gates, valves, pipe spillways, lake drains, internal drain pipes, and other structural steel elements.

Frequently, corrosion is a significant problem with metal conduits, pipe and riser spillways, and drains. The type of pipe (smooth steel, corrugated metal, ductile iron, etc.), the protective coating or corrosion protection system, and the wall thickness of the metal are factors which determine the corrosion rate and significance. Seepage around a metal pipe at the outlet end may be an indicator of corrosion if joints are known to be watertight. Both water quality and soil conditions are other factors affecting the rate of metal corrosion. Metal conduits through embankment dams need to be examined with special care for signs of corrosion. Corrosion holes and perforations could allow water into the surrounding embankment from the conduit, or into the conduit from the embankment. Either of these situations can result in piping through the embankment.

Corrosion of mechanical parts such as valve stems and guides could prevent operation of a drain or gate system in an emergency. A gate or valve broken during operation can also result in the unexpected draining of the impoundment and the danger of a sudden drawdown, which could trigger earth slides. Inspecting personnel should be alert and try to identify the most likely cause of corrosion. Design errors, poor maintenance, severe weather conditions or a change in water quality could be contributing factors.

Corrosion may manifest itself in a number of different ways. For discussion, it is convenient to use the “eight forms of corrosion" as described by Fontana and Greene in Corrosion Engineering. These eight forms are described below.

(1) Uniform Attack - The most common form of corrosion. Proceeds uniformly over a

large area. Results in uniform thinning of the surface and eventual failure if not controlled.

(2) Galvanic or Bimetal Attack - Formed when different metals from the galvanic series are coupled. Corrosion is predictable according to the galvanic series.

(3) Crevice Corrosion - Often intense and localized. May occur under gaskets, within lap joints, under surface deposits, mud, or other detritus.

(4) Pitting Corrosion - Intense, highly localized corrosion resulting in holes of relatively small diameter and large depth. May result in penetrations and leaks.

(5) Intergranular Corrosion - Most often noted in or near improperly executed welds in stainless steels. May appear as "knife line" corrosion (as if the metal has been slit) or as thinning of the material in the heat-affected zone adjacent to the weld.

(6) Selective Leaching - The removal of one material from a solid alloy by corrosion. In cast iron, the removal of iron from the alloy, leaving only the carbon matrix (graphitization). In brasses, the removal of aluminum or zinc from the alloy (de-alumification or dezincification). In either case, the remaining material has little strength.

(7) Erosion Corrosion and Cavitation - Deterioration of metals because of high velocity impingement on the surface. Results in directional pits and grooves.

(8) Stress Corrosion - Often results in cracking of highly stressed materials (bolts, for example) in corrosive or mildly corrosive environments. Failure can be unanticipated and catastrophic. Stress corrosion cracking can also occur in improperly heat treated metals. The failure of the component could be at a load that is much less than the intended design.

Common methods of protecting metals from corrosion include protective coatings (paint) and cathodic protection. A third method is used in the design process by incorporating, in the construction, materials that are immune from corrosion in the particular environment expected. Unfortunately, except for occasional replacement of parts, this method is unavailable to the operator of an existing structure.

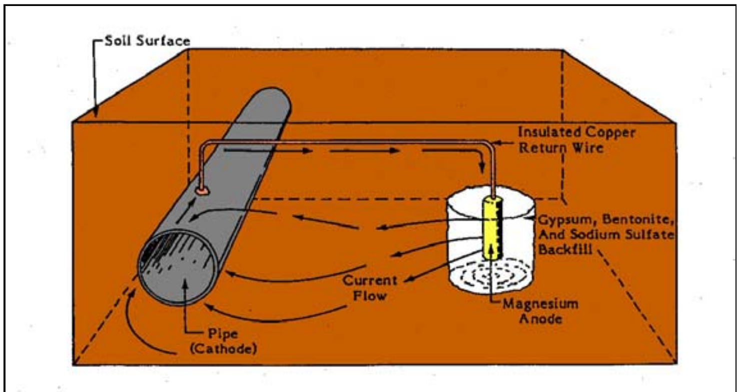


Figure 6-32 Illustration of cathodic protection of buried a metal pipe.

Metal pipes are available which have been coated to resist accelerated corrosion. Coatings can be of epoxy, aluminum, zinc (galvanized), or asbestos. Coatings applied to pipes in service are generally not very effective because of the difficulty in establishing a bond. Bituminous coatings cannot be expected to last more than one or two years (in flowing water.

Corrosion of metal can also be controlled or arrested by installing cathodic protection (see Figure 6-32). A metallic, sacrificial anode such as magnesium, zinc, or aluminum is buried in the soil and is connected to the metal pipe by wire. Degradation of the anode produces an electrical current that flows from the magnesium (anode) to the pipe (cathode) and will cause the magnesium to corrode and not the pipe. Another method of cathodic protection consists of the impressed current system. An impressed current system includes a rectifier that converts an alternating power supply to a direct current that is properly calibrated to provide the required protection. Since the power source is delivered to the anode and is not generated by its degradation, the impressed current system can be calibrated to meet the site's conditions. Current can be automatically and continuously adjusted to meet varying conditions. Voltage provided by sacrificial anodes is too high when new and too low when old, so the impressed current system provides a means for supplying the right amount of current at all times. However, the best way to avoid corrosion in spillway conduits is to not use metal pipes.

Corrosion of metal parts of operating mechanisms may be effectively treated and prevented by keeping these parts greased and/or painted. The inspector should look for these signs of preventive maintenance, and recommend that they be implemented if not currently used.

Most of the metal corrosion that the inspector observes during a visual inspection will probably be a maintenance concern only. He/she should be able to recognize when corrosion is a potential safety issue that threatens the safety of the dam.

Some structures are especially crucial to dam safety. Metal corrosion becomes hazardous when it renders critical metal structures inoperable. Inoperable gates, valves, or cranes and hoists endanger a dam when the ability to release flood flows is hindered and the dam is in jeopardy of being overtopped. Corrosion that is not particularly severe or extensive may interfere with operation or bind moving mechanical parts.

Table 6-7
Likely Sites for Corrosion

- Missing or damaged protective coatings
- Areas where metal has been rolled to shape rather than cast, or has been bent or distorted, including:
  - Angle supports
  - Rolled plates
  - Distortions from riveting Welded areas
  - Parts misaligned during assembly
- Contacts between dissimilar metals causing galvanic corrosion, including:
  - Gate arms, connections, and chains of incompatible metals
  - Steel screws in brass
  - Lead solder around copper wire
  - Steel shaft rotating in bronze bearings
  - Broken rust or mill scale (iron oxide) allowing galvanic reaction with exposed steel
  - Dissimilar metals embedded in concrete, such as aluminum conduit and steel reinforcing (aluminum should not be embedded in concrete)
- Sites where moisture and limited oxygen supply on the metal surface create conditions for galvanic corrosion, including:
  - Under accumulations of dirt or other surface contaminations
  - In crevices (crevice corrosion) such as joints and cracks, rivet holes, gaskets, and valve seats
  - Under coatings (underfilm corrosion destroys coating integrity, allowing corrosion to accelerate)
- Areas of high velocity flows, such as in pressurized sections of conduit, downstream from gates and valves, on needle and tube valves, on outlet pipes in the vicinity of gates, and in locations of sudden changes of direction or flow cross-section
- Locations where metal is cracked due to tensile or dynamic stress, such as in gates, gate seal bars, gate and bridge supports, metal flashboards and stop logs, valves, valve stems, gate and valve operators, and moving parts on cranes and hoists such as rods and connecting pins
- Buried conduits, including joints where new sections of conduit were inserted adjacent to older sections

Metal girders used as supports for an operating or access bridge might buckle if weakened by extensive corrosion and preclude access to gate or valve controls. Inability to operate spillway gates during a flood could cause the dam to overtop.

Pitting can perforate a metal conduit and allow water to erode an embankment dam from within. Pay careful attention to areas where coating is missing or defective. A very small opening in a coating can result in severe, concentrated corrosion at that spot.

Test the operation of gates and valves at regular intervals and during any formal technical inspection. Testing operation is the best way to determine if corrosion is hindering the proper functioning of these devices (the owner should perform all testing).

If the inspector observes metal corrosion, he/she should:

- Photograph and record location, type, and extent of the deterioration. Note prominent features, and whether other damage is also present.
- Look for structural damage, including misalignment, settlement, vertical and horizontal displacement.
- Look for any surrounding damage to structures or foundation.
- Classify and describe the corrosion using the terminology previously defined.
- Consult a corrosion specialist if:

  (1) Hazardous metal corrosion may endanger the dam either because the corrosion site is sensitive to relatively small degrees of corrosion (as in a mechanical device such as a gate) or because the corrosion is severe and extensive enough to cause a metal structure to fail.

  (2) It is suspected that metal has been lost to corrosion on an inaccessible surface, such as the outside of buried metal conduit. Ultrasonic thickness measuring equipment operated from the opposite side can estimate metal thickness, but the extent of pitting corrosion is difficult to determine because damage tends to be highly localized. The conduit may need to be excavated for thorough examination.

- Evaluate pitting, a common form of corrosion, by counting the number of pits (if sites are few) or by using a system of rating charts, which are based on the percentage of pitted area.
- Document all observations and recommend corrective action and timing.

6.5.3.2 Cracking and Deformation

Cracking in metal is a separation into two or more parts, while deformation is the bending or twisting of a metal object into other than its design shape.

Metal cracking and deformation tend to afflict mechanical devices, such as cranes and hoists, or structures subjected to static and dynamic stress, such as gates and valves.

Uneven hoist pull is a possible cause for gate frame and lifting beam distortion, broken gate connections, and broken lifting chain or wire rope. Deep or extensive cracking indicates that failure due to tearing and rupture may be imminent, while deformations may interfere with mechanical operations. During flooding or other emergencies, inoperable equipment could endanger a dam by being unable to release flood flows.

Metal cracking and deformation usually include three types of deficiencies: (1) cracking and stress corrosion cracking; (2) fatigue and corrosion fatigue; and (3) overload failure.

Cracking and corrosion in metals may be closely related; stress corrosion cracking and corrosion fatigue involve both corrosion and mechanical forces. Stress corrosion cracking results from a combination of tensile stress and a mildly corrosive environment. The inspector should look for signs of stress under corroded areas to determine if there was a mechanical force involved that caused fatigue of the metal.

Fatigue is loss of metal strength from repetitive bending, known as corrosion fatigue when combined with corrosion. The affected area weakens, cracks, and then tears or ruptures. Sharp notches and reentrant corners without fillets are often points (called "stress risers") where a crack starts.

An overload failure results from a single stressing beyond the tensile, shear, or compression strength of a metal part. An example is a conduit or liner buckling due to an internal vacuum or external pressure.

During dam safety visual inspections, the inspector probably will observe far more corrosion than cracking and deformation of metals. Cracking and deformation usually affect the integrity of a metal part, and therefore are likely to be hazardous to the safety of a dam.

Table 6-8
Likely Sites for Metal Cracking and Deformation

- Gates
  - Gate connections
  - Gate side guides
  - Lifting lugs or attachments
  - Lifting chain or wire rope
    - Kinks in wire rope
    - Failure at bends in wire rope
    - Defective plastic coating on wire rope
    - Failure at connections
  - Roller train components (tractor gates)
  - Vanes supporting hollow-cone valves
  - Gates
  - Lifting beams
- Conduits
  - Welded joints
  - Fittings
  - Conduit lining
  - Conduit coating
  - Conduit

Measure conduit height and width to detect "egg-shaped" or oval conduit flattened by heavy loads. Look for cracks in the conduit, the lining, and the coating caused by stress concentrations.

If the inspector observes metal cracking or deformation that may affect the safety of the dam, he/she should:

- Photograph and record the extent, location, and possible causes of cracks and deformations.
- Compare observations with prior inspection reports
- Consult a qualified dam safety professional for further evaluation and proposed corrective measures.

6.5.3.3 Metal Coatings

Metal coatings are coating systems that have been specifically formulated to adhere to metal (or other materials) and protect it from corrosion. Metal coating systems for dams and associated structures (penstocks, power plants, administrative and maintenance structures, etc.) can be divided into four general categories:

(1) Coating systems that will be fully immersed in water or covered with backfill (buried)
(2) Coating systems that will be both immersed in water and subjected to atmospheric exposure
(3) Coating systems that will receive exterior atmospheric exposure only
(4) Coating systems that will receive interior atmospheric exposure only

Some coating systems overlap one or more of the above categories. Although it is possible that exposure to severe chemicals, saltwater, severe chemical fumes, or salt spray could be encountered, and a coating system that would resist these types of exposure would be required, it is not likely that such exposure conditions would be experienced with freshwater dams and dam-related structures in Indiana.

Coating systems control corrosion in one or more of the following ways:

- Creating a barrier between the metal and corrosive agents in the environment. It is important to realize that there is no such thing as a completely and indefinitely impervious coating system.
- Gradually releasing corrosion-inhibiting chemicals.
- Sacrificial action in which the sole or major component of the coating, such as zinc, sacrifices itself to protect the metal underneath. The coating in effect provides a kind of cathodic protection.

Defective or missing protective coatings expose metal parts and structures to corrosion and, therefore, to ultimate failure. Failure of metal structures such as gates, bridges, and conduits can result in dam failures.

All coatings systems fail prematurely for one or more of the following reasons:

- Poor surface preparation (very frequent cause)
- Poor application procedures (frequent cause)
- Improper specification of a coating system for the underlying metal or exposure conditions it will be facing in the field (infrequent cause)
- Defective or off-standard coating system materials as a result of mistakes or contamination during their manufacture (infrequent cause)
- Physical or mechanical damage, resulting from impacts, cavitation, or erosion from water carrying abrasive sediment

Identifying and quantifying metal coating system deficiencies is accomplished by periodic visual inspection of the applied coatings. This inspection is relatively easily accomplished on the coating systems that are exposed to the atmosphere, either indoors or outdoors, and are reasonably accessible. Visual inspections of immersed coating systems on gates, the interiors of penstocks, etc., can be accomplished only when those structures have been dewatered. Buried coating systems on the exteriors of pipe or other structures cannot be directly inspected unless they have been uncovered for some reason. If there is a corrosion monitoring system in place, the coating systems can be indirectly inspected for their general conditions. Among the tools required for the visual inspections are: a knife, a magnifying glass, and a thickness gauge. A pit gage or other means of measuring, or at least reasonably estimating, the depth of pits is also necessary.

The first areas to exhibit coating failure are usually welds, bolt heads, edges, and areas where access is difficult. The thickness gauge is used to measure decreases in coating system thickness from erosion, chalking, and abrasion. Thicknesses are usually measured in thousandths of an inch (mils). (As a point of comparison, a dollar bill is about 4 mils thick.) Pitting is often the most serious defect and can cause rapid failure of piping or other structures while a major portion of the remaining metal is intact. This defect can be very serious in a metal conduit running through an embankment dam, for example, because the escaping water can erode the dam from within. Measuring the depth of pits enables a calculation to be made of the pit depth versus the thickness of the steel.

A knife is one of the best and most important inspection instruments for checking corrosion and pitting. It is necessary for removing corrosion so that pitting can be measured, and for removing loose coating system material so that corrosion undercutting of the coating system film can be discovered. A knife is a good instrument for checking adhesion to see how much adequately bonded coating is left if there is local peeling or other signs of removal of the coating system. It can also be used to check flexibility and discover embrittlement of coating system films, and to break blisters to check the condition of the metal underneath.

Quantification of coating system defects can be accomplished by using ASTM pictorial methods. These methods are available in *Pictorial Standards of Coating Defects* published by the Federation of Societies for Coatings Technology (FSCT). Pictorial standards are available for blistering, chalking, checking, cracking, erosion, filiform corrosion, flaking, mildew, and rusting. Both a number and a description are given, such as No.4-medium dense blisters. Through the use of these standards it is possible to convey the appearance of a coating system defect to people who have not witnessed it personally. It is very important to accurately record the locations of defects. An imaginary grid system can be used as long as the location of the grids is recorded. Another method is verbal description, such as upper left or center left of a gate whose dimensions are given. In pipes the distance and direction from reference points, such as the pipe outlet or manholes, can be given.

Recording the results of both scheduled and unscheduled coating system visual inspections is extremely important. The records of the coating systems on all structures must begin with the coating systems that were originally applied. A complete history must be kept of all the coating systems that have been applied to the structures, including records of touchups. An existing system must be over coated or touched up with a compatible coating. The records can track the rate of deterioration of coating systems and make pre-planned maintenance and recoating possible. Also, the records can supply the information required for decisions on whether to touch up, repair and overcoat, or remove the existing coating system to metal, prepare the surface, and completely recoat with the same or a different coating system.

6.5.3.4 Cavitation

Cavitation damage can be detected visually in areas where cavitation is likely to occur. It is distinguished by the loss of material in a pitting pattern which appears as though the lost material was "sucked" off or, in some instances, by removal of the coating system and evidence of attack on the metal underneath.

Cavitation is likely to occur at the same locations in metal pipes as in concrete pipes, as described earlier. Cavitation may be reduced by introducing air through a vent pipe at a point downstream of the control valve, where a pressure drop is expected. The vent pipe establishes atmospheric pressure so that a partial vacuum is not created, and cavitation is avoided.

Cavitation is also found on valve surfaces.

6.5.4 Conduit and Pipe Special Concerns

This subchapter provides more specific information on spillway and outlet conduits and pipes in addition to the other information presented earlier.

Figure 6-33 Inspecting a spillway that has flowing water is very difficult.

Many dams have conduit systems that serve as principal spillways and outlets. These conduit systems are required to carry normal stream and flood flows safely past the embankment throughout the life of the structure. Conduits through embankments are difficult to construct properly and can be extremely dangerous to the embankment if problems develop after construction. Conduits are usually difficult to inspect and repair because of their location within the embankment. Also, replacing conduits requires extensive excavation. In order to avoid difficult and costly repairs, particular attention should be directed to maintaining these structures. The most common problem noted with spillway conduit systems is undermining of the conduit. This condition typically results from water leaking through pipe joints, seepage along the conduit or inadequate energy dissipation at the conduit outlet. The typical causes of seepage and water leaking through pipe joints include any one or a combination of the following factors: loss of joint material, separated joints, misalignment, differential settlement, conduit deterioration, and pipe deformation. Problems in any of these areas may lead to failure of the spillway system and possibly dam failure.

Undermining is the removal of foundation material surrounding a conduit. Any low areas or unexplained settlement of the earthfill in line with the conduit may indicate that undermining has occurred within the embankment. As erosion continues, undermining of a conduit can lead to displacement and collapse of the pipe sections and cause sloughing, sliding or other forms of instability in the embankment. As the embankment is weakened, a complete failure of the conduit system and, eventually the dam may occur. Undermining along the entire length of conduit is referred to as piping.

In addition, undermining can occur as the result of erosion due to inadequate energy dissipation or inadequate erosion protection at the outlet. This undermining can be visually observed at the outlet of a pipe system and can extend well into the embankment. In this case, undermining can lead to other conduit problems such as misalignment, separated joints and pipe deterioration.

Figure 6-34 The outlet of this spillway has been undermined from the erosive forces of the discharge water.

The inspector should look for signs of undermining and piping, including sinkholes, water seepage, loss of pipe-joint material, sediment build-up at the outlet, and movement of pipe sections.

Seepage along the conduit from the reservoir can occur as a result of poor compaction around the conduit. If seepage control devices have not been installed, the seepage may remove foundation material from around the conduit and eventually lead to piping. Seepage is usually easy to spot around conduits.

Pipe deformations are typically caused by external loads that are applied on a pipe such as the weight of the embankment or heavy equipment. Collapse of the pipe can cause failure of the joints and lead to erosion of the supporting fill. This may lead to undermining and pipe settlement. Pipe deformation may reduce or eliminate spillway capacity. Pipe deformation must be monitored on a regular basis to ensure that no further deformation is occurring, that pipe joints are intact and that no undermining or settlement is occurring. A common cause of pipe deformation is inadequate compaction of fill under and around the conduit.

Conduit systems usually have construction and/or section joints. In almost every situation, the joints will have a water stop, mechanical seal and/or chemical seal to prevent leakage of water through the joint. Separation and deterioration of the joints can destroy the watertight integrity of the conduit system. Joint deterioration can result from weathering, excessive seepage, erosion or corrosion. Deterioration at joints includes loss of gasket material, loss of joint sealant, and spalling around the edges of joints. Separation at a joint may be the result of a more serious condition such as foundation settlement, undermining, structural damage, or structural instability. Separated pipe joints can be detected by inspecting the interior of the conduit. Both separation and deterioration of joints allow seepage through the conduit. The seepage can erode the fill underneath and along the conduit causing undermining, which can lead to the displacement of the pipe sections or embankment piping. A visual inspection program is needed to determine the rate and severity of joint separation and deterioration. Joint separations should be monitored on a regular basis to determine if movement is continuing.

Deterioration of conduit material is normally due to the forces of nature such as wetting and drying, freezing and thawing, oxidation, decay, ultra-violet light, cavitation, and the erosive forces of water. Deterioration of pipe materials and joints can lead to seepage through and along the conduit and eventually failure of conduit systems.

Removal or consolidation of foundation material from around the conduit can cause differential settlement. Inadequate compaction immediately next to the conduit system during construction may compound the problem. Differential settlement can ultimately lead to undermining of the conduit system or embankment piping. Differential settlement should be monitored with visual inspections and documentation of observations.

Alignment deviations can be an indication of movement, which may or may not be in excess of design tolerances. Proper alignment is important to the structural integrity of conduit systems. Misalignment can be the direct result of internal seepage flows that have removed soil particles or dissolved soluble rock. Misalignment can also result from poor construction practices, collapse of deteriorated conduits, decay of organic material in the dam, seismic events, or normal settlement due to consolidation of embankment or foundation materials. Excessive misalignment may result in other problems such as cracks, depressions, slides on the embankment, joint separation, and seepage. Both the vertical and horizontal alignment of the conduit should be inspected on a regular basis.

All conduits should be inspected thoroughly once a year as part of the maintenance inspection program. Conduits that are 30 inches or more in diameter can be entered and visually inspected with proper ventilation and confined space precautions. Small inaccessible conduits may be monitored with video cameras. The conduits should be inspected for misalignment, separated joints, loss of joint material, deformations, leaks, differential settlement, and undermining. Problems with conduits occur most often at joints, and special attention should be given to them during the visual inspection. The outlet should be checked for signs of water seeping along the exterior surface of the conduit. Generally, this is noted by water flowing from under the conduit and/or the lack of foundation material directly beneath the conduit. The embankment surface should be monitored for depressions or sinkholes. Depressions or sinkholes on the embankment surface above the spillway conduit system develop when the underlying material is eroded and displaced. The inspector should photograph all problems that are observed in the conduits.

Accessible portions of conduits, such as the outfall structure and control, can be easily and regularly inspected. However, several problems are commonly associated with deterioration or failure of portions of the system which are either buried in the dam or normally under water. The following are some general guidelines for inspecting conduits:

- Conduits that are 30 inches or greater in diameter can be inspected internally, provided the system has an upstream valve, allowing the pipe to be dewatered. Tapping the conduit interior with a hammer will help locate voids which may exist behind the pipe. This type of inspection should be performed at least once a year during maintenance inspections.
- Small diameter pipes can be inspected by remote TV camera. The camera is moved through the conduit and transmits a picture to an equipment truck, where it can be viewed by a technician. This type inspection is expensive and usually requires the services of an engineer. However, if no other method of visual inspection is possible, the use of TV equipment is recommended at least once every five years.
- Outlet intake structures, wet wells, and outlet pipes with only downstream valves, are the most difficult to inspect because they are usually under water. These should be scheduled for visual inspection when the reservoir is drawn down or at five year intervals. If a definite problem is suspected, or if the reservoir remains full over extended periods, divers should be hired to perform an underwater inspection.

6.5.5 Testing the Outlet System

Outlets should be operated at least twice per year and especially prior to the onset of the flood season (typically March in Indiana) to verify their performance and to help keep them in operating order. Unused outfall valves and controls can become corroded or blocked with sediment, so routine testing can help maintain these devices. The following guidelines can be used when testing outlet works:

(1) All valves should be fully opened and closed at least twice per year. This limits corrosion build-up on control stems and gate guides and provides an opportunity to check for smooth operation of the valve. Stiff or erratic valve operation could indicate problems, requiring more detailed inspection.

(2) The system should be checked through the full range of gate settings. Slowly open the valve, checking for noise and vibration. Certain valve settings may result in greater turbulence. Check for noise that sounds like gravel being rapidly transported through the system. This sound indicates that cavitation is occurring. Note the operating range that produces this noise, and, if possible, avoid operating under these gate settings.

(3) Check the operation of all mechanical and electrical systems associated with the outlet. Backup electric motors, power generators, and power and lighting wiring should function as intended and be in a safe condition.

The outlet, or lake drain, should always be operable so that the pool level can be drawn down in case of an emergency or for necessary repair. Lake drain valves or gates that have not been operated for a long time present a special problem for owners. If the valve cannot be closed after it is opened, the impoundment could be completely drained. An uncontrolled and rapid drawdown could also induce more serious problems such as slides in the saturated upstream slope of the embankment. Drawdown rates should not exceed 1 foot per day for slopes of clay or silt material except for emergency situations. Very flat slopes or slopes with free-draining upstream zones may be able to withstand more rapid drawdown rates. Large discharges could also cause downstream flooding. Therefore, before operating a valve or gate, it should be inspected and all appropriate parts lubricated and repaired. It is also prudent to advise downstream residents of large and/or prolonged discharges.

To test a valve or gate without risking that the lake will be drained, the inlet upstream from the valve must be blocked. Some drain structures have been designed with this capability and have dual valves or gates, or slots for stoplogs (sometimes called bulkheads) located upstream of the drain valve. Divers can be hired to inspect the drain inlet, and may be able to construct a temporary block at the inlet for testing purposes. Early detection of equipment problems or breakdowns, and confidence in equipment operability, are benefits of periodic operation.

Sediment is another problem that may be encountered when operating the lake drain. Sediment deposits can build up and block the drain inlet. Debris can be carried into the valve chamber, hindering its function if an effective trash rack is not present. The potential that this problem will occur is greatly decreased if the valve or gate is operated and maintained periodically.

Many older dams have drains with valves at the downstream end. If the valve is located at the downstream end of a conduit extending through the embankment, the conduit is under the constant pressure of the reservoir. If a leak in the conduit develops within the embankment, saturation, erosion, and possibly failure of the embankment could occur in a short period of time. A depression in the soil surface over the pipe may be a sign soil is being removed from around the pipe. These older structures should be monitored closely and owners should plan to relocate the valve upstream or install a new drain structure. Inspectors should closely examine the drain outlet for signs of possible problems when valves are located at the downstream end of the drain.

6.5.6 Mechanical Equipment

Mechanical equipment includes spillway gates, sluice gates or valves, stoplogs, sump pumps, flash boards, relief wells, emergency power sources, siphons and other equipment associated with spillways, drain structures, and water supply structures. Stoplogs, flashboards, and siphons are not necessarily mechanical equipment, but are included in this category because they could be, and the equipment used to implement them usually is. Mechanical and associated electrical equipment should be checked for proper lubrication, smooth operation, vibration, unusual noises, and overheating. The adequacy and reliability of the power supply should also be checked during operation of the equipment. Auxiliary power sources and remote control systems should be tested for adequate and reliable operation. All equipment should be examined for damaged, deteriorated, corroded, cavitated, loose, worn, or broken parts.

Gate stems, guides, and couplings should be examined for corrosion, loose, broken or worn parts, and damage to protective coatings. Fluidways, leaves, metal seats, guides, and seals of gates and valves should be examined for damage due to cavitation, wear, misalignment, corrosion, and leakage. Sump pumps should be examined and operated to verify reliability and satisfactory performance. Air vents for pipes, gates and valves should be checked to confirm that they are open and protected. Wire rope or chain connections at gates should be examined for proper lubrication and worn or broken parts. Rubber or neoprene gate seals should be examined for deterioration or cracking.

Hydraulic hoists and controls should be checked for oil leaks and wear. Hoist piston and indicator stems should be examined for contamination and for rough areas that could damage packings.

Many dams have structures above and below ground that require some type of access. Water supply outlet thimble works, lake drains, gated opening spillways, drop box spillways, and toe drain manhole interceptors are typical structures that will require bridges, ladders, or walkways. Care should be taken to properly design, install, and maintain these means of access for the safety of persons using them. Access requirements for walkways may include toe plates and handrails. Fixed ladders should have proper rung spacing and safety climbing devices, if necessary. Access ladders, walkways, and handrails should be examined for deteriorated or broken parts or other unsafe conditions.


Figure 6-35 Wood flashboards exhibiting leakage.

Stoplogs, bulkhead gates, and lifting frames or beams should be examined to determine their availability and condition. The availability, operability, and locations of equipment for moving, lifting, and placing stoplogs, bulkheads, and trash racks should also be verified.

Flashboards are usually wood boards installed in an upright position along the crest of the spillway to raise the normal pool level. Flashboards should not be installed or allowed unless professional investigation indicates there is sufficient freeboard remaining to safely pass the design flood. Some flashboard installations are designed to fail when subjected to a certain depth of flowing water, thereby recovering the original spillway capacity. However, flashboards designed to fail may not be reliable and are not recommended. Maintenance generally consists of repairing or replacing broken boards. The support structure for the flashboards should be examined for damage due to wear, misalignment, corrosion, and leakage, and repaired as necessary. The flash-boards should be removed periodically (at least once a year) as a check for freedom of movement and deterioration of the boards. Leakage is a common problem. Unless there are extenuating circumstances, flashboards should be removed prior to the onset of flood season (typically March in Indiana) and reinstalled when conditions permit.

6.5.7 Earth and Rock Materials

6.5.7.1 Earth Spillways

Figure 6-36 Severe erosion in earth outlet channel adds sediment to receiving stream.

When inspecting an earth spillway, the inspector should determine whether side slopes have sloughed, or whether there is excessive vegetative growth in the channel. The entrance and exit of the spillway should be unobstructed by trees, brush, or general vegetative overgrowth; during severe flooding, accumulation of drift in these areas can significantly reduce spillway capacity, increase erosion and contribute to overtopping of the dam and possible failure. The inspector also should look for signs of erosion and rodent activities. Use a probe to obtain a comparative feel of the hardness and moisture content of the soil. Note the location of particularly wet or soft spots. See if the stilling basin or drop structure is properly protected with rocks or riprap. Since some erosion is unavoidable during discharge of water, determine whether such erosion might endanger the embankment. If the spillway is installed with a sill, determine if there is any cracking or misalignment of the sill. Also look for any erosion beneath or downstream of the sill.

If spillway side walls slide and block the spillway entrance or channel, the dam may become susceptible to overtopping because of reduced capacity to pass flood flows. Erosion of plunge pools and return channels may expose the toe of the dam to erosion, undercutting, and subsequent slope failure.

6.5.7.2 Rock Cuts

Figure 6-37 Spillway constructed in a rock cut.

Dams built in areas where rock is at or near the surface may include outlet works and spillway channels and tunnels constructed in or through the rock. Fallen rock may block discharges through a tunnel or channel, or rock falling into the reservoir immediately upstream from the dam could render outlet works, penstocks, or spillways inoperable. Abutment movement may restrict or prevent operation of appurtenances located in or on the abutment. Loosened rock could block or damage structures in their fall paths. Any of these conditions may cause the dam to be overtopped.

Rock deficiencies can be described by one of the following categories:

- Inadequate hardness or strength
- Discontinuities (faults, shears, joints, bedding planes)
- Weathering, or deterioration (temperature variations (thermal stresses), freeze-thaw action, erosion, plant and animal activity, chemical action)
- Solutioning (chemical weathering of mineral or rock into solution by seepage flow)

Excavated rock slopes and tunnel walls are subject to spalling and weathering from freeze-thaw action. Rock contains joints (also called fractures or discontinuities) along which water can pass, resulting in deterioration. Movement at these joints caused by an earthquakes or excess hydrostatic pressure may result in large rock falls.

The inspector should be alert for potentially large rock falls, slides, and resulting obstruction of tunnels and spillway channels. These potentially hazardous conditions are typically caused by instability of rock slopes, degradation of rock slopes, seepage from cut faces, and deficient rock reinforcement.

Slope instability in rock spillways usually results in slides or movement on the slopes. Look for signs of rock movement at fractures and joints which might indicate a future rock fall or slide. Movement is often indicated by fresh cracks on the rock surface, cracks in dam concrete where it joins the rock, blocks falling from abutments, displacement of vegetation, and arc-shaped cracks on or above slopes. Slides on slopes adjacent to spillways are especially hazardous because of the potential for blockage, or damage to the structure preventing operation. In rock abutments adjacent to a concrete dam, look for freshly exposed rock at or near the dam-abutment contact. Check any instrumentation data that may exist for indications that rock walls or slopes have moved. Movement of abutment rock can be very serious, possibly resulting in loss of support for the dam. If data show progressive movement and increasing seepage pressure, the dam and abutments may be in danger of destabilization.

Degradation of rock slopes is usually easy to spot. Look for evidence of past rock falls, and check the floors of rock-cut spillways and unlined rock tunnels for excessive amounts of rock chips and pieces. Examine the walls for general deterioration. If there is evidence that portions of a concrete structure have moved due to thermal or chemically induced expansion or other causes, check rock abutments adjacent to the structure for spalling and possible crushing of rock at joints and fractures caused by pressure from concrete movement.

Seepage from rock cuts or from the floor of spillways cut in rock can create a number of potentially unsafe conditions. The inspector should evaluate the rate of seepage, correspondence of seepage rates to reservoir level, staining, and turbidity of seepage to fully understand the problem. Seepage can create excess hydrostatic pressure, weaken the overall strength of the rock walls, and produce increasingly large channels for water flow. Openings can enlarge sufficiently to cause slope movement or collapse. Stains from seepage water indicate solutioning of minerals which may reduce the shearing strength of the rock materials and cause rock consolidation. The inspector should take samples of the seepage so that the minerals can be identified. The inspector should also check the geologic data for evidence of deposits of limestone or other rock subject to solutioning that may underlie competent rock. Turbid flow indicates that internal erosion or piping is occurring. The inspector should check the construction records to see if rock walls and slopes were grouted to control seepage. If grouting was not done in the past, this procedure may control the seepage. If prior grouting proved inadequate to prevent or control seepage, a qualified dam safety professional should examine possible causes and sources of the seepage and evaluate corrective actions.

Deficient rock reinforcements, if used, can also result in slope stability problems in spillways cut in rock. Rock reinforcements such as bolts, anchors, dowels, and tendons may be installed in the rock tunnels and slopes of dams. Be sure to make a record of deficient rock reinforcements, including deterioration of the rock around fastening plates, loose bolts or plates, and corroded bolts, fastening plates, or wire grids (especially in the vicinity of seepage).

If the inspector observes rock deficiencies that may affect the safety of a dam, he/she should:

- Record the location and extent of the deficiencies, and photograph the affected areas.
- Determine the cause of the damage, if possible.
- Notify a qualified dam safety professional immediately if abutment movement or a rockfall in an unlined tunnel or spillway channel is suspected or observed.

6.5.7.3 Riprap

Riprap is deficient when it fails to protect the underlying earth from erosion. Many riprap deficiencies can be dealt with through routine maintenance, such as adding rock to areas where riprap has started to become displaced. More severe riprap deficiencies may threaten the safety of the dam. Undercutting by wave action, slides, and slope failure can lead to failure of a spillway channel, a plunge pool, or, if erosion continues unchecked, even the breaching of an embankment dam or dike.

Figure 6-38 Riprap degradation.

Riprap may suffer from displacement or rock degradation. These deficiencies may be related, with degradation often leading to displacement.

Displacement of riprap or the underlying slope material results from the removal of rocks from their as-placed position. Filter or bedding material may become exposed, or the riprap layer may become thinner, providing inadequate protection. Reasons riprap can become displaced include:

- Inadequate thickness of riprap layer
- Improper sizing or gradation of riprap relative to filter or bedding material (inner layer is washed through outer layer)
- Improper anchorage at base of protected slope
- Loss of foundation support
- Missing, inadequate, or improperly sized filter or bedding material
- Wrong shape (too slabby/flat, or too round: most problems are due to stones being too round and easily rolled by waves or flows)
- Rock weight insufficient (due to small size or low specific gravity) for anticipated wave action or flow velocity
- Too much variance in size and weight
- Average weight reduced by rock deterioration
- Nondurable rock
- Damage from ice movement in the reservoir
- Bedding not properly installed
- Poor grading of slope
- Improper foundation preparation
- Rock sizes segregated during placement
- Loose placement resulting in large voids

Rock degradation may be caused by high abrasion loss, structural weakness (cracks, fractures, etc.), high absorption rates (freeze-thaw damage from absorbed water), and impact damage from debris. Types of rock degradation include cracking, spalling, splitting or delaminating along bedding planes and joints, de-aggregating and disintegrating of poorly cemented sedimentary rock, and dissolving.

Riprap installations in areas exposed to numerous freeze-thaw cycles or high winds are most likely to experience serious problems. Be especially alert for riprap problems if the dams being inspected are exposed to these conditions.

Riprap exposed to high velocity flows or turbulence on a spillway channel, or in the lining of a plunge pool, is especially vulnerable. Rock may be displaced, or may degrade by becoming weathered and breaking down, thereby allowing damage to the underlying slope.

All riprap degrades over time, but wetting and drying, and freeze-thaw cycles accelerate degradation in spillway and outfall structures. Look for signs that the riprap is smaller near the waterline, that rocks are shattered, or that thinning of the riprap layer or gaps in the riprap have developed. The riprap layer may be so degraded and displaced that erosion of the underlying material has begun.

If riprap deficiencies that may affect the safety of the dam are observed, the inspector should:

- Record the location and approximate dimensions of riprap deficiencies.
- Look for signs of foundation and bedding deterioration.
- Photograph the area.
- Recommend temporary corrective actions.
- Consult a qualified dam safety professional to evaluate the need for major repair.

6.5.7.4 Gabions

Gabions may be used as lining and support in spillways, stilling basins, and other dam outfall structures. A gabion is a prefabricated rectangular wire cage or basket filled in place with rocks. Gabions are free-draining and capable of being stacked for erosion protection. The term "gabion wall" may be used to refer to stacked gabions, while "gabion mattress" refers to a layer of gabions used to protect a chute or basin floor.

Figure 6-39 Gabion baskets before installation.

Gabions are usually subject to various deficiencies that may cause deformation and possible toppling of gabion walls. These deficiencies include inadequate foundation support, foundation erosion, settlement of the rock within the basket, rock degradation, and failure of the wire baskets. Settlement and possible displacement of gabions can result from inadequate foundation support or from erosion of the subgrade. Foundation

Figure 6-40 Gabion-lined emergency spillway.

soils may be eroded when gabions are used because water flow can occur at the bottom of the basket. Proper foundation treatment is essential when gabions are installed in waterways. Rock within a gabion can shift and consolidate into a smaller space than when the basket was filled, creating unsupported space at the top of the basket. Rocks within gabions may spall, split, disintegrate, or dissolve. Flowing water can then wash pieces of rock through openings in the basket. The loss of rock mass makes the gabions susceptible to being lifted and moved by flows, and consolidation of rock within the basket creates empty, unsupported space at the top of the basket. The wires of the baskets may become corroded, broken or cut by vandals, or deformed by rapidly flowing water. Rocks may be washed out of a damaged basket, and the basket can be deformed by the weight of shifting rocks or other gabions, and fail.

Failure of gabion channel protection may result in exposure of slopes or channel floors to erosion, undercutting, and subsequent failure. When gabion structures consist of stacks or rows of baskets, the integrity of individual baskets is crucial to the integrity of the structure. Baskets are prone to deformation because basket wires can bend, corrode, and break, and stones can shift, deteriorate, or be dislodged.

Some settlement of a gabion installation is normal. Gabions are designed to be flexible and allow for some degree of settling. Minor deterioration in a gabion installation generally constitutes a long-term maintenance problem rather than a hazard to the dam. Hazardous gabion deficiencies are those that destabilize the installation, or cause it to fail entirely, usually because of deficiencies in a limited number of baskets.

The lower baskets in a vertical or battered gabion wall support the greatest weight, and are most likely to become deformed. Because of their position, failure of lower baskets carries great potential to destabilize a gabion installation. Defects such as broken, cut, or deformed wires and missing rock can lead quickly to failure of the individual gabion and subsequent failure of a wall. Look for damaged baskets or baskets crushed by overlying gabions, and for movement and for undermining caused by waves or current.

If the inspector observes gabion deficiencies that may affect the safety of the dam, he/she should:

- Record the location and extent of defective areas, and describe the nature of the deficiency; i.e., basket wires broken, degree of deformation or settlement, approximate amount of missing rock, etc.
- If the underlying slope is exposed, record the extent of slope damage, using such measurements as the length, width, and height of the affected area.

- Photograph the damaged area.
- Recommend corrective action and timing.

6.5.8 Synthetic Materials

Synthetic materials are often used in spillways and outlet works for discharge (conduits or pipes), drainage and seepage control (geotextile separators, geomembrane liners), and for filter media. Synthetic materials are also commonly referred to as geosynthetic materials because they are often used to replace earth materials in construction. In general, synthetic materials are not visible for examination during inspection. The inspector will detect most deficiencies in synthetic materials by noting indirect signs, such as changes in drainage amounts, or foundation erosion.

Synthetic materials used at dams generally fall into in three broad categories: (1) geotextiles, (2) geomembrane linings, and (3) plastic piping and tubing (often referred to as geopipes).

Table 6-9
Common Deficiencies in Geotextiles and Geomembranes

- Punctures and damage
  - Spreading equipment
  - Installation of anchorage fasteners
  - Construction or maintenance activities
  - Dropping riprap without cushioning
- Seams unbonded or poorly bonded
  - Seams opened under load
  - Poor bond between new and old fabric
- Sections incorrectly positioned or overlapped
- Displacement (usually slippage down slope)
- Soil piping through broken or open seams or punctures
- Clogging with soil particles (geotextiles only)
- Design problems
  - Lack of strength or durability for intended use
  - Incorrect match to soil base (improper filtering)
  - No anchorage provided
  - Inadequate transmission of water (Inadequate porosity)
- Defective materials
  - Lack of specified strength or durability
  - Holes or weak areas
- Deterioration
  - Aging
  - Temperature extremes (especially at or below the freezing point)
  - Exposure to ultraviolet light (sunlight)
  - Adverse chemical or biological conditions

A deficiency in a geotextile or geomembrane lining may severely affect the integrity of the incorporating structure. In the case of geotextiles within a dam, the deficiency could cause the dam to fail from internal erosion or piping. Deficiencies of geotextiles used for slope protection could result in a slope failure. The deficiency may affect a structure crucial to the safe operation of a dam, such as a spillway or plunge pool.

Inspectors are usually most successful with detection of deficiencies in geotextiles and geomembrane linings in dams when they record the amount of seepage at drains and check the clarity of the water that is collected. If seepage has decreased and water pressure within the embankment has increased, as measured by a piezometer, geotextiles within the embankment may be clogged. Undrained seepage may be building hydrostatic pressure inside the embankment, weakening soil strength, or eroding the embankment. Turbid flow indicates piping and loss of material.

The following subchapters describe specific safety concerns for the various synthetic materials that may be used at dams and spillways.

6.5.8.1 Geotextiles


Figure 6-41 Articulating blocks are being placed over a geotextile filter on a dam embankment.

Geotextiles are water permeable, are generally made from polypropylene or polyester, and can be woven, nonwoven, or a combination of woven and nonwoven segments. Uses for geotextiles include separation between layers of materials, drainage, reinforcement, and filtration. In dams, geotextiles may have temporary or permanent construction uses. Geotextiles placed as embankment dam core and foundation filters would be extremely difficult to replace if problems develop, and such uses have generally not been embraced by the profession as accepted applications.

Geotextiles are sometimes used in lieu of granular filters beneath other erosion control materials such as riprap. Protected slopes may be on the dam embankment or surfaces in spillways and plunge pools.

Geotextiles serve to control or prevent the movement of soil fines under riprap or similar materials used for slope protection and for lining spillways and plunge pools. Punctures and other deficiencies may result in loss of bedding material and erosion of foundation material beneath the geotextile, leading to sunken areas and voids under the riprap.

When a geotextile fails, the failure may jeopardize the structure which incorporates the geotextile. If seepage in a protected slope is restricted from entering a collector drain because of a clogged geotextile, excessive hydrostatic pressure could develop in the embankment or slope which could lead to slope failure. A ruptured geotextile could lead to piping of the embankment material because the filtering capacity is lost, at least locally.

Clogging of geotextiles under riprap may cause a buildup of hydrostatic pressure at the toe, saturating the slope, and potentially resulting in a local failure that is seen as bulging at the slope toe until the geotextile breaks. After the geotextile breaks, a washed-out area will develop.

If deficiencies in geotextiles that could affect the safety of the dam are observed, the inspector should:

- Photograph and record the observations that indicate possible problems with the geotextiles.
- Determine the function of the geotextile, and the cause of the problem.

- Refer problems with geotextiles to a qualified dam safety professional.

6.5.8.2 Geomembranes

Geomembrane linings are impermeable, and are typically used as water barriers. Geomembrane linings may be composed of various materials, the most commonly used being PVC (polyvinyl chloride), CSPE-R (chlorosulfonated polyethylene-reinforced), HDPE (high density polyethylene), VLDPE (very low density polyethylene), and neoprene. Dams with seepage problems may deploy a geomembrane on the upstream face of the dam to control seepage. Geomembranes are not commonly used at dams or spillway structures.

A failed geomembrane reservoir liner can permit seepage through porous foundation zones which might cause piping to develop.

Figure 6-42 A geomembrane liner being installed in a waste water reservoir.

For reservoirs sealed with a geomembrane liner, unaccountable losses from the reservoir may be the first clue that the liner is leaking. Seepage around the reservoir rim is another indicator. The inspector should examine the reservoir floor with the reservoir drawn down if possible. Examine the protective layer over the membrane liner for gaps, plant growth, animal burrows, damage from vandalism, and piercing of the liner.

If deficiencies in geomembrane linings that could affect the safety of the dam are observed, the inspector should:

- Photograph and record the observations that indicate possible problems with the geomembrane linings.
- Determine the cause of the problem.
- Refer indications of geomembrane lining failure to a qualified dam safety professional.

6.5.8.3 Geopipes

Plastic piping and tubing (geopipes) have been used in dam spillway and outlet works, although this practice is not recommended in Indiana. Furthermore, plastic pipes have not been proven to be safe in spillway applications. Most geopipes are made of PVC (polyvinyl chloride), ABS (acrylonitrile butadiene styrene), and PE (polyethylene).

Plastic pipe is used for conveying water and other fluids, but the pipe must be protected from mechanical damage. Plastic piping and tubing usually are embedded in concrete or buried underground for protection.

Common uses for plastic piping and tubing include:

- Piezometer tubing used to measure water pressure in earth structures or foundations and abutments
- Tubing in stilling wells
- Electrical conduit
- Seepage collectors in drainage systems (PE)
- Outlet works conduits (PE and PVC); plastic pipes are not recommended

Table 6-10
Types of Geopipe Deficiencies

Mechanical damage

- Cracks
- Breaks
- Split seams
- Disbonded fitting/joints
- Poorly welded joints
- Shear at wall-backfill interface
- Crushing by stones in backfill or vehicles driven on embankment, or other loads
- Burned or deformed when exposed in areas where surface vegetation is controlled by burning

Deterioration

- Exposure to ultraviolet light (sunlight)
- Chemical attack
- Stress-deformation (creep), buckling
- Localized sources of high heat, including burning

Deficiencies of plastic pipes that affect the safety of the dam generally involve drainage systems. Malfunction of plastic pipes used as seepage collectors in drainage systems could result in excess or leaking drainage water building hydrostatic pressure inside the embankment, the dam, or in the foundation, causing a loss of strength, reduction of safety against slope failure or sliding, and possible failure at the downstream toe or slope. Seepage also may erode soil from within the dam or foundation into a broken or damaged collector system.

The inspector should check for safety deficiencies in plastic pipe used in drainage systems. Past inspection reports and other documentation may contain drainage measurements to compare with current observations. Signs of potentially hazardous conditions in plastic piping and tubing include leaking fittings and joints, visible impact damage, warp or creep, silted or obstructed flow area, plugged outlets obstructing free flow (lack of flow - operates only during wet weather), crushed pipe, burned surfaces, and turbidity or sediments in the discharge.

Figure 6-43 Plastic pipe used as the principal spillway; this is not a recommended practice.

When inspecting unexposed pipe, reduced flow, turbid flow, or lack of flow are indicators of possible problems with the pipe. The following procedures can be used to help identify problems with unexposed or buried pipes:

- Pull a plug through the pipe to test for obstructions (if open at two ends)
- Inspect the pipe interior using a remotely operated video or television camera
- Use a motorized drain cleaning tool to clear possible obstructions
- For a pipe that should be watertight, pressurize the pipe with air or water, and check the pressure to detect leaks (not recommended unless very low pressures are used, since a sudden break or release could damage the embankment)

If a deficiency in plastic piping and tubing that may affect the safety of the dam is observed, the inspector should:

- Record the observations and procedures used to investigate changes in drainage patterns.
- Describe any findings about the causes of the deficiency, and possible corrective actions.
- If the apparent volume of leakage into the embankment is sizable, consult a qualified dam safety professional for further evaluation.

6.6 OBSTRUCTIONS

Obstructions can reduce the capacity or operation of spillways and outlets. Obstructions of surface features are usually easy to detect. However, obstructions within buried or submerged conduits and other structures may not be readily apparent. The spillway, the approach to the spillway, and the downstream exit channel could be obstructed by excessive growth of grass and weeds, thick brush, trees, debris, or landslide deposits. An obstructed spillway will have a substantially reduced discharge capacity. This reduced capacity can create serious problems, including embankment overtopping or complete dam failure.

Earthen emergency spillways are particularly prone to excessive vegetative growth. There should be no trees, shrubs, or brush in any emergency spillway. Man-made structures, unless considered in the original design for spillway adequacy, should not be built in emergency spillways. The inspector should always recommend the removal of trees, shrubs, and other obstructions in the emergency spillway. Figure 6-44 shows a spillway discharge channel with excessive trash. Figure 6-45 shows a building constructed in

Figure 6-44 Trash in this spillway outlet channel obstructs the flow.

an emergency spillway.

Figure 6-45 A building constructed in the emergency spillway obstructs flow and poses a safety risk to the building.

Grass is usually not considered as an obstruction. But tall weeds and brush should be periodically cleared and trees removed as soon as they are noticed. Brush and debris can be entangled with trees to form an effective obstruction. When this happens, an even and smooth flow pattern cannot be maintained. Consequently, the effective width and capacity of the spillway could be reduced and the potential for erosion increased.

Any substantial amount of dirt deposited in the spillway channel from sloughing, a landslide above the channel, or sediment transport into the area must be immediately removed. Timely removal of large rocks is especially important. Presence of rocks in the channel can obstruct flow and encourage erosion. A sudden plunge of the spillway to the stilling basin also results in abrasion of the channel lining and damage to the stilling basin.

Figure 6-46 Excessive vegetation obstructs this riser structure.

Walls of spillways are usually equipped with weep (or drain) holes. Occasionally, spillway chute slabs are also equipped with weep holes. If all holes are dry, it is probably because the soil behind the wall or below the slab is dry. If some holes are draining while others are dry, then the dry holes may be plugged by mud or mineral deposits. Probe the plugged hole to determine probable causes of the blockage. Plugged weep holes increase chances for failure of the retaining wall or chute slab. Try to clean out dirt or deposits and restore draining ability. If this does not work, rehabilitation work must be performed under the supervision of a qualified dam safety professional as soon as possible.

Figure 6-47 Inappropriate trash rack over end of a culvert spillway.

Many dams in Indiana have pipe and riser spillways. Pipe spillway inlets that become plugged with debris or trash reduce spillway capacity. As a result, the potential for overtopping the dam is greatly increased, particularly if there is only one spillway. If the dam has an emergency spillway channel, a plugged principal spillway will cause more frequent and greater than normal flow in the emergency spillway. Since emergency spillways are generally designed for infrequent flows of short duration, serious damage may result. For these reasons trash collectors or racks must be installed at the inlets to pipe spillways and lake drains and trash must be removed whenever it restricts the inlet capacity.

Figure 6-48 Poorly constructed trash rack has openings that are too large at the riser crest.

A well-designed trash rack will stop large debris that could plug the discharge pipe but allow unrestricted passage of water and smaller debris. Some of the most effective racks allow flow to pass beneath the trash into the riser inlet as the pool level rises. Racks usually become plugged because the openings are too small, or the head loss at the rack causes material and sediment to settle out and accumulate. Small openings will stop small debris such as twigs and leaves, which in turn cause a progression of larger items to build up, eventually completely blocking the inlet. Trash rack openings should be at least 6 inches across regardless of the pipe size. The larger the principal spillway conduit, the larger the trash rack opening should be. The largest possible openings should be used, up to a maximum size of about 2 feet.

Figure 6-49 Riser lacking a trash rack can clog and cause dam overtopping.

The trash rack should be properly attached to the riser inlet, and strong enough to withstand the hammering forces of debris being carried by high velocity flow, a heavy load of debris, and ice forces. If the riser is readily accessible, vandals could throw riprap stone into it. To prevent such vandalism, the size of the trash rack openings should not be decreased, but rock that is larger than the openings or too large to handle should be used in the vicinity of the riser.

The lack of a trash rack is unacceptable, and creates the potential for an extremely hazardous condition. Trash racks constructed from very thin wire, such as “chicken wire," that can be easily damaged or destroyed is also unacceptable. Trash racks that are "flat" and cover only the opening of a riser (i.e. constructed similar to a grate over a drop inlet on streets) are also safety concerns because of the potential for clogging. In either case, the inspector should recommend the installation of a proper trash rack.

Maintenance should include periodically checking the trash rack for rusted and broken sections, and repairing it as needed. The trash rack should be checked frequently during and after storm events, to ensure it is functioning properly, and to remove accumulated debris.

Figure 6-50 Beavers have blocked this spillway.

Vegetated earth spillways are commonly used as an economical means to provide emergency spillway capacity. Normal flows are carried by the principal spillway, and infrequent large flood flows pass primarily through the emergency spillway. For dams with pipe-conduit spillways, an emergency spillway is almost always required as a back-up in case the pipe becomes plugged. These spillways are often neglected because the owner rarely sees them flow. Beavers may present problems at dams where they may live. Beavers have a natural tendency to block off spillways with brush and sticks.

Figure 6-51 Trees growing in emergency spillway.

Periodic mowing in the grass-lined spillways is required to prevent trees, brush, and weeds from becoming established, and to encourage the growth of grass. Poor vegetal cover will usually result in extensive, rapid erosion when the spillway flows, and will require more costly repairs. Trees and brush may reduce the discharge capacity of the spillway. The inspector should evaluate the degree of vegetative growth in the earthen spillways. Tree and shrub removal should always be recommended if these plants are present.

Erosion can be expected in the spillway channel during high flows, and can also occur as a result of rainfall and local runoff. The latter is more of a problem in large spillways, creating gullies where low flows tend to concentrate, and may require special treatment, such as terraces or pilot channels. Erosion of the side slopes deposits material in the spillway channel, especially where the side slopes meet the channel bottom. In small spillways, this can significantly reduce the spillway capacity. This condition often occurs immediately after construction, before vegetation becomes established. In these cases, it may be necessary to reshape the channel to provide the necessary capacity.

Emergency spillways often are used for purposes other than passage of flood flows.

Among these uses are reservoir access, parking lots, boat ramps, boat storage, pasture and cropland. Permanent structures (buildings, fences, etc.) should not be constructed in these spillways.

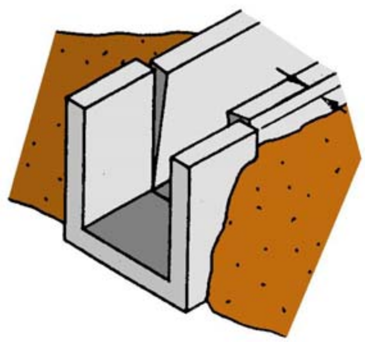
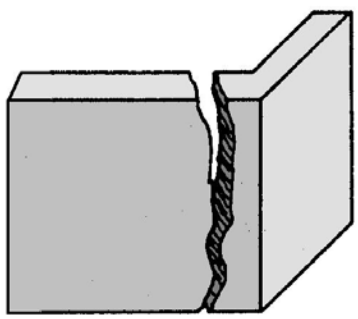
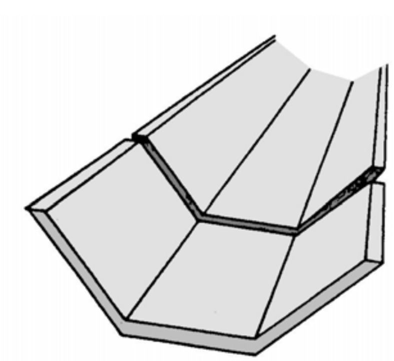
During inspection of spillways and outlets for obstructions, the inspector should:

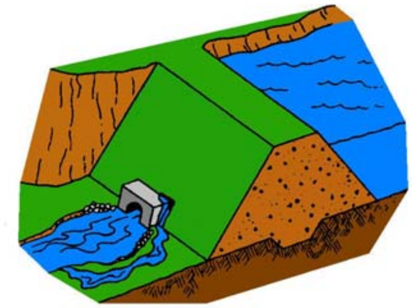
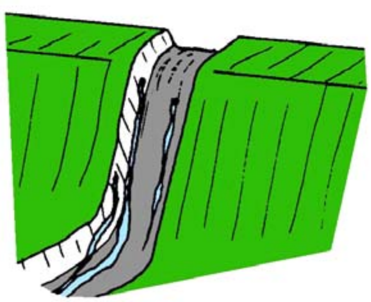
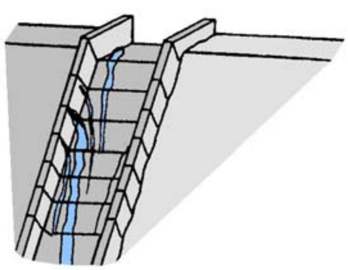
- Describe the location, type and extent of any obstruction that may be present.
- Photograph the obstruction.
- Recommend corrective action and timing.

6.7 SPILLWAY AND OUTLET INSPECTION SKETCHES

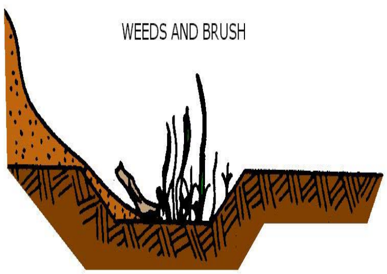
The following pages contain sketches of conditions that may be found on the spillway or outlet of the dam during an inspection. While most of the conditions on the following tables can be corrected by routine and periodic maintenance conducted by the owner, some of the conditions noted are of a nature that threaten the safety and integrity of the dam and require the attention of a qualified dam safety professional (if immediate emergency action is not required). Depending on the severity of the condition, the dam owner may need to take immediate action to prevent the condition from worsening, including contacting repair contractors, notifying local emergency authorities, and notifying downstream residents or occupants. A qualified dam safety professional is a person with specific expertise in the field of concern. For example, an engineer or geologist with geotechnical or geological experience may need to be consulted if a slope stability or soil issue exists. Or, an engineer with hydrologic and hydraulic experience will be required to determine spillway capacity.

Information on materials used in spillway outlet pipes and valves is included at the end of the sketches.

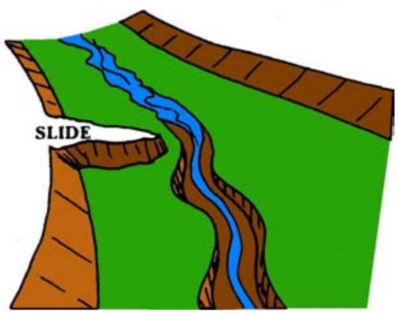
PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED
WALL DISPLACEMENT 	**Probable Cause**: Poor workmanship; uneven settlement of foundation; excessive earth and water pressure; insufficient steel bar reinforcement of concrete. **Harm**: Minor displacement will create eddies and turbulence in the flow, causing erosion of the soil behind the wall. Major displacement will cause severe cracks and eventual failure of the structure.	**Potential Action**: Reconstruction or replacement should be done according to sound engineering practices. Foundation should be carefully prepared. Adequate weep holes should be installed to relieve water pressure behind wall. Use sufficient reinforcement in the concrete. Anchor walls to prevent further displacement. Install struts between spillway walls is required. Clean out and backflush drains to assure proper operations. Consult an engineer before actions are taken. *Qualified Dam Safety Professional Required*
LARGE CRACKS 	**Probable Cause**: Construction defect; local concentrated stress; local material deterioration; foundation failure, excessive backfill pressure. **Harm**: Disturbance in flow patterns; erosion of foundation and backfill; eventual collapse of structure.	**Potential Action:** Large cracks without large displacement should be repaired by patching. Surrounding areas should be cleaned or cut out before patching material is applied. Installation of weep holes or other actions may be needed. Replacement may be required in some cases.
OPEN OR DISPLACED JOINTS 	**Probable Cause**: Excessive and uneven settlement of foundation; sliding of concrete slab; construction joint too wide and left unsealed. Sealant deteriorated and washed away. **Harm**: Erosion of foundation material may weaken support and cause further cracks; pressure induced by water flowing over displaced joints may wash away wall or slab, or cause extensive undermining.	**Potential Action:** Construction joint should not be wider than 0.5 inches. All joints should be sealed with asphalt or other flexible materials. Water stops should be used where feasible. Clean the joint, replace eroded materials, and seal the joint. Foundation should be properly drained and prepared. Underside of chute slabs should have ribs of sufficient depth to prevent sliding. Avoid steep chute slope. *Qualified Dam Safety Professional Required*

PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED
SEEPAGE WATER EXITING FROM A POINT ADJACENT TO THE OUTLET 	**Probable Cause**: 1. A break in the outlet pipe. 2. A path for flow from the reservoir has developed along the outside of the outlet pipe. **Harm**: Continued flows can lead to rapid erosion of embankment materials and failure of the dam.	**Potential Action:** 1. Thoroughly investigate the area by probing and/or shoveling to see if the cause can be determined. 2. Determine if leakage water is carrying soil particles. 3. Determine quantity of flow. 4. If flow increases or is carrying embankment materials, reservoir level should be lowered until leakage stops. 5. A qualified engineer should inspect the condition and recommend further actions to be taken. *Qualified Dam Safety Professional Required*
LEAKAGE IN OR AROUND SPILLWAY 	**Probable Cause**: 1. Cracks and joints in geologic formation at spillway are permitting seepage. 2. Gravel or sand layers at spillway are permitting seepage through embankment. **Harm**: 1. Could lead to excessive loss of stored water. 2. Could lead to a progressive failure if velocities are high enough to cause erosion of natural materials.	**Potential Action:** 1. Examine exit area to see if type of material can explain leakage. 2. Measure flow quantity and check for erosion of natural materials. 3. If flow rate or amount of eroded materials increases rapidly, reservoir level should be lowered until flow stabilizes or stops. 4. A qualified engineer should inspect the condition and recommend further actions to be taken. *Qualified Dam Safety Professional Required*
SEEPAGE FROM A CONSTRUCTION JOINT OR CRACK IN CONCRETE STRUCTURE 	**Probable Cause**: 1. Water from reservoir is collecting behind or under structure because of insufficient drainage or clogged weep holes. 2. Lack of cutoff wall. **Harm**: 1. Can cause walls to tip in and over. Flows through concrete can lead to rapid deterioration from weathering. 2. If the spillway is located within the embankment, rapid erosion can lead to failure of the dam.	**Potential Action:** 1. Check area behind wall for puddling of surface water. 2. Check and clean as required: drain outfalls, flush lines, and weep holes. 3. If condition persists, a qualified engineer should inspect the condition and recommend further actions to be taken. *Qualified Dam Safety Professional Required*

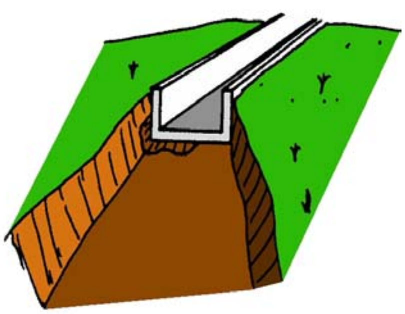
PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED
DEBRIS OR OTHER OBSTRUCTIONS	**Probable Cause**: Accumulation of slide materials, dead trees, excessive vegetative growth, etc., in spillway channel. **Harm**: Reduced discharge capacity; overflow of spillway; overtopping of dam. Prolonged overtopping can cause failure of the dam.	**Potential Action:** Clean out debris periodically; control vegetative growth in spillway channel. Install log boom in front of spillway entrance to intercept debris.



PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED
EXCESSIVE EROSION IN EARTH-SLIDE CAUSES CONCENTRATED FLOWS	**Probable Cause**: 1. Discharge velocity too high; bottom and slope material loose or deteriorated; channel and bank slopes too steep; bare soil unprotected; poor construction; protective surface failed. 2. Engaged too frequently. **Harm**: Disturbed flow pattern; Joss of material, increased sediment load downstream; collapse of banks; failure of spillway; can lead to rapid evacuation of the reservoir through the severely eroded spillway.	**Potential Action:** Minimize flow velocity by proper design. Use sound material. Keep channel and bank slopes mild. Encourage growth of grass on soil surface. Construct smooth and well compacted surfaces. Protect surface with riprap, asphalt, or concrete. Repair eroded portion using sound construction practices.

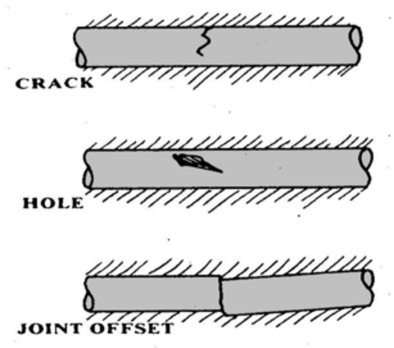


PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED
END OF SPILLWAY CHUTE UNDERCUT	**Probable Cause**: Poor configuration of stilling basin area. Highly erodible materials. Absence of cutoff wall at end of chute. **Harm**: Structural damage to spillway structure; collapse of slab and wall; leads to costly repair. Higher velocity flows can cause erosion of drain, then embankment materials.	**Potential Action:** Dewater affected area; clean out eroded area and properly backfill. Improve stream channel below chute; provide properly sized riprap in stilling basin area. Install cutoff wall.



PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED

OUTLET PIPE DAMAGE



Probable Cause:

Crack:

Settlement; impact, improper design or placement.

Hole:

Rust (steel pipe)

Erosion (concrete pipe)

Cavitation

Joint offset:

Settlement or poor construction practice.

Harm:

Provides passageway for water to exit or enter pipe.

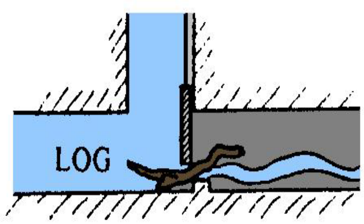
For all conditions:

Check for evidence of water either entering or exiting pipe at crack/ hole/etc.

Tap pipe in vicinity of damaged area, listening for hollow sound which indicates a void has formed along the outside of the conduit.

If a progressive failure is suspected, request qualified professional assistance.

DEBRIS STUCK UNDER GATE



Probable Cause:

Trash rack missing or damaged.

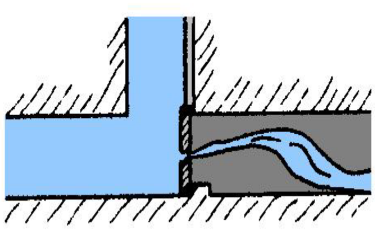
Harm:

Gate will not close. Gate or stem may be damaged in effort to close gate.

Potential Action:

Raise and lower gate slowly until debris is loosened and floats past valve. When reservoir is lowered, repair or replace trash rack.

CRACKED GATE LEAF



Probable Cause:

Ice action, rust, impact, vibration, or stress resulting from forcing gate closed when it is jammed.

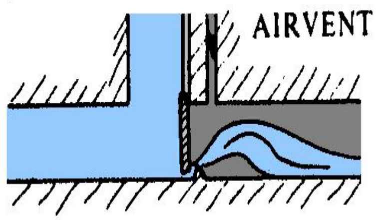
Harm:

Gate-leaf may fail completely, evacuating reservoir.

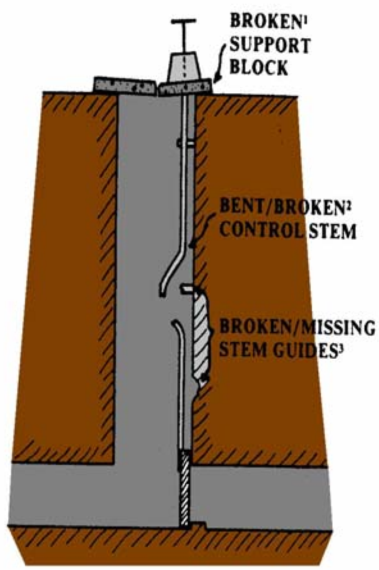
Potential Action:

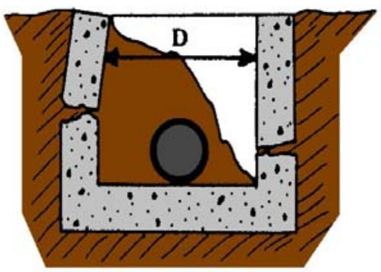
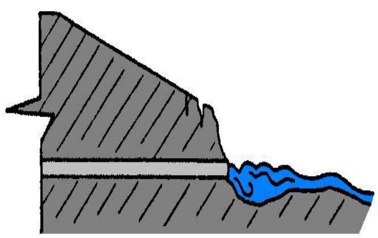
Use valve only in fully open or closed position. Minimize use of valve until leaf can be repaired or replace.

PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED
DAMAGED GATE LEAF OR GUIDE	**Probable Cause**: Rust, erosion, cavitation, vibration, or wear. **Harm**: Leakage and loss of support for gate leaf. Gate may bind in guides and become inoperable.	**Potential Action:** Minimize use of valve until guides/ seats can be repaired. If cavitation is the cause, check to see if air vent pipe exists, and is unobstructed.



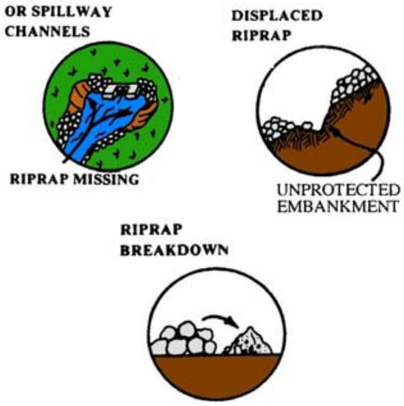
CONTROL WORKS	**1. BROKEN SUPPORT BLOCK:** **Probable Cause**: Concrete deterioration. Excessive force exerted on control stem by attempting to open gate when it was jammed. **Harm:** Causes control support block to tilt; control stem may bind. Control headworks may settle. Gate may not open all the way. Support block may fail completely, leaving outlet inoperable. **2. BENT/BROKEN CONTROL STEM:** **Probable Cause**: Rust. Excess force used to open or close gate. Inadequate or broken stem guides. **Harm:** Outlet is inoperable. **3. BROKEN/MISSING STEM GUIDES:** **Probable Cause**: Rust. Inadequate lubrication. Excess force used to open or close gate when it was jammed. **Harm:** Loss of support for control stem. Stem may buckle and break under even normal use, (as in this example).	**Potential Action:** Any of these conditions can mean the control is either inoperable or at best partially operable. Use of the system should be minimized or discontinued. If the outlet system has a second control valve, consider using it to regulate releases until repairs can be made. Engineering assistance is recommended.



PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED
FAILURE OF CONCRETE OUTFALL STRUCTURE 	**Probable Cause**: Excessive side pressures on non-reinforced concrete structure. Poor concrete quality. **Harm**: Loss of outfall structure exposes embankment to erosion by outlet releases.	**Potential Action:** Check for progressive failure by monitoring typical dimension, such as "d" shown in figure. Repair by patching cracks and providing drainage around concrete structure. Total replacement of outfall structure may be required.
OUTLET RELEASES ERODING TOE OF DAM 	**Probable Cause**: Outlet pipe too short. Lack of energy-dissipating pool or structure at downstream end of conduit. **Harm**: Erosion of toe over-steepens downstream slope, causing progressive sloughing.	**Potential Action:** Extend pipe beyond toe (use a pipe of same size and material, and form watertight connection to existing conduit). Protect embankment with riprap over suitable bedding.

PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED

Breakdown or loss of riprap



Probable Cause:

Slope too steep; material poorly graded; failure of sub-grade; flow velocity too high; improper placement of material; bedding material or foundation washed away.

Harm:

Erosion of channel bottom and banks; failure of spillway.

Potential Action:

Design a stable slope for channel bottom and banks. Riprap material should be well graded (the material should contain small, medium, and large particles). Sub-grade should be properly prepared before placement of riprap. Install filter fabric if necessary. Control flow velocity in the spillway by proper design. Riprap should be placed according to specification. Services of an engineer are recommended.

Qualified Dam Safety Professional Required

Material deterioration-spalling and disintegration of riprap, concrete, etc.

Probable Cause:

Use of unsound or defective materials; structure subjected to freeze-thaw cycles; improper maintenance practices; harmful chemicals.

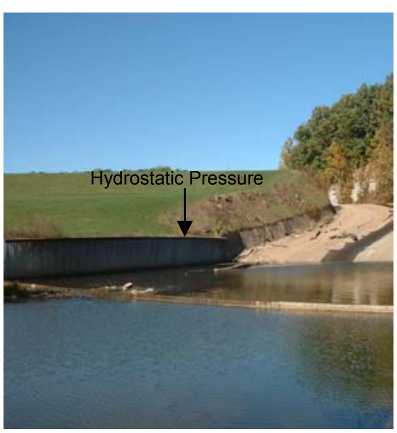
Harm:

Structure life will be shortened; premature failure.

Potential Action:

Avoid using shale or sandstone for riprap. Add air-entraining agent when mixing concrete. Use only clean good quality aggregates in the concrete. Steel bars should have at least 1 inch of concrete cover. Concrete should be kept wet and protected from freezing during curing. Timber should be treated before use.

Poor surface drainage



Probable Cause:

No weep holes; no drainage facility; plugged drains.

Harm:

Wet foundation has lower supporting capacity; uplift pressure due to accumulated seepage water may cause damage to spillway chute; accumulation of water may also increase total pressure on spillway walls and cause damage.

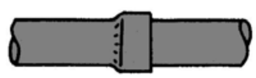
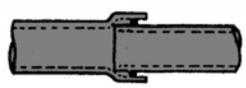
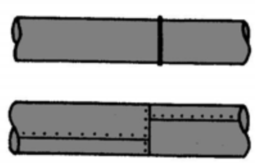
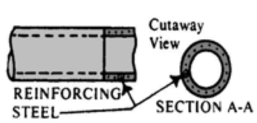
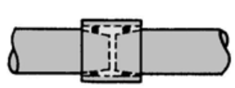
Potential Action:

Install weep holes on spillway walls. Inner end of hole should be surrounded and packed with graded filtering material. Install drain system under spillway near downstream end. Clean out existing weep holes. Back flush and rehabilitate drain system under the supervision of an engineer.

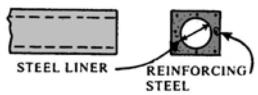
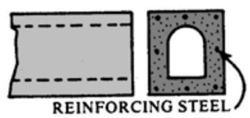
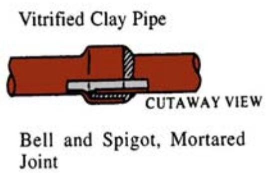
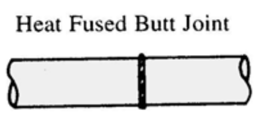
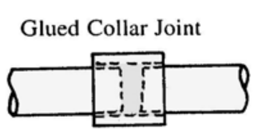
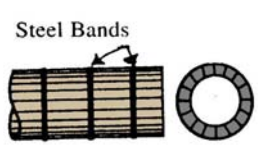
Qualified Dam Safety Professional Required

PROBLEMS	CAUSES & HARM DONE	ACTION REQUIRED
Concrete erosion, abrasion, and fracturing 	**Probable Cause**: 1. Flow velocity too high (usually occurs at lower end of chute in relatively high dams); rolling of gravel and rocks down the chute; cavity behind or below concrete slab. 2. Absence of cutoff wall. **Harm:** Pock marks and spalling of concrete surface may progressively become worse; small hole may cause undermining of foundation, leading to failure of structure.	**Potential Action:** Remove rocks and gravels from spillway chute before flood season. Raise water level in stilling basin. Use good quality concrete. Make sure concrete surface is smooth. *Qualified Dam Safety Professional Required*

MATERIALS USED IN OUTLET PIPES

<u>**TYPE**</u> **[METAL PIPES]**	**DRAWING OR DESCRIPTION**	**ADVANTAGES**	**DISADVANTAGES**
1. CMP	Corrugated Metal Pipe 	Low cost. Light weight. Flexibility.	Not watertight; can't be used as pressurized pipe. Requires tar protection to inhibit rusting. Subject to structural collapse under high loading. Roughness reduces capacity. Not recommended.
2. CAST IRON	Bell and Spigot Joint With Gasket 	Durable. History of satisfactory service commonly exceeds 100 years. Oxides of corrosion adhere and help protect the pipe from further attack. High strength.	Brittle and difficult to weld; cracks if subjected to severe impact or ice action. Tubercu-lation (formation of rust mod-ules) decreases pipe inside diameter and increases rough-ness; cement lining usually desirable.
3. DUCTILE IRON	Bell and Spigot Joint With Gasket 	High strength with some flex-ibility; not brittle like cast iron. (Other advantages similar to cast iron.)	Tuberculation. (See Cast Iron.)
4. STEEL		High strength and flexibility without cracking. Easily welded for water-tight connection. Forms good liner for concrete encased pipe.	Failure by rusting or chemical attack; oxides flake-off, expos-ing pipe to further attack. Surface protection required. Coating should be applied.
[CONCRETE PIPES]			
1. RCP	Reinforced Concrete Pipe 	High strength. Not subject to corrosion. Rubber gasket joints form watertight connection.	Brittle; can chip or crack if subjected to impact or differ-ential settlement. Heavy; dif-ficult to handle. Subject to erosion by sediment washed through pipe.
2. ACP	Asbestos-Cement Pipe  Collar Joint With Gaskets	Will not corrode; contains no metal or organic material. Light weight; easy to install.	Brittle; can be broken by impact or differential settlement.

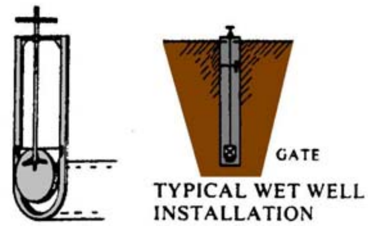
MATERIALS USED IN OUTLET PIPES

TYPE	**DRAWING OR DESCRIPTION**	**ADVANTAGES**	**DISADVANTAGES**
[CONCRETE PIPES]			
3. CONCRETE ENCASED PIPE	 	Adds strength to the steel conduit, by surrounding it with reinforced concrete. If the liner rusts out, outlet can usually be repaired by relining.	Added cost.
4. CAST-IN-PLACE CONCRETE CONDUIT	 	High strength. Any size or shape can be constructed.	Special forming required; added cost.
[MISCELLANEOUS MATERIALS]			
1. VCP	 	Will not corrode. Smooth interior; less resistance to flow.	Brittle; pipe and joints easily damaged by impact or differential settlement. Not normally used as pressure pipe; joints may leak. Not recommended for any use.
2. POLYETHYLENE	 	Flexible and very tough; will not develop stress cracks. Lightweight and will not corrode. Very smooth; little resistance to flow. Watertight.	Limited in-place testing. May collapse or creep under high loading; concrete encasement may be required.
3. PVC	 	Lightweight and inexpensive. Easy assembly; no special tools. Smooth and will not corrode.	Limited in-place testing. May "sunburn" and become brittle if exposed to sunlight for extended periods of time. Recommended for underdrains only; do not use as spillway or outlet conduit.
4. WOOD STAVE	 	Will not rust. Smooth and not damaged by freezing. Lightweight.	Relatively short life unless kept saturated. High cost of maintenance. Seldom used in current design. High leakage; low strength. Not recommended for any use.

OUTLET VALVES

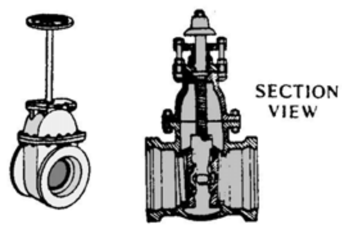
TYPE | **DRAWING OR DESCRIPTION** | **USES AND DISCUSSION**

SLIDE GATE OR SLUICE GATE



The most common type of valve. Used as regulating or guard valve at upstream end of outlet pipe, or in wet well. Mechanically simple and available in a variety of sizes and shapes. Suitable for dams of low to moderate height. If used to regulate flow, an air vent is recommended just downstream of the valve.

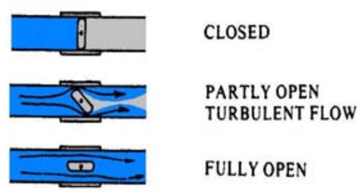
GATE VALVE



Typically used as a regulating valve or guard valve at the upstream end of the conduit or in an outlet well. Since the valve is watertight, the outlet well remains dry. The gate leaf is wedge-shaped and seals into a tapered seat.

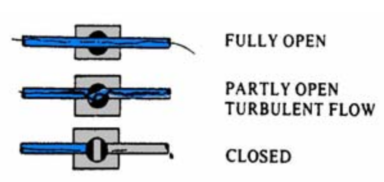
If a gate valve is used for regulation, an air vent is recommended just downstream of the valve.

BUTTERFLY VALVE



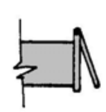
Performs best as an upstream guard gate. If used for regulation, certain valve openings cause turbulence and cavitation. Air vent required downstream of valve, if used for regulation.

BALL VALVE, PLUG VALVE, OR CONE VALVE

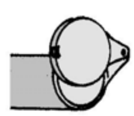


Used in low head situations or as a guard valve. Intermediate valve settings may result in turbulence and cavitation (air vent recommended).

FLAP GATE, SHEAR GATE



FLAP GATE



SHEAR GATE

Used as guard gate at end of outlet conduit. Normally in the fully open position. Valve is closed only to dewater the outlet conduit for maintenance, inspection, or in an emergency. Prevents backwater from flowing into the pipe.